

SOIL SAMPLING AND TESTING FOR TRANSPORTATION ENGINEERING TECHNICIANS



TRAINING MANUAL

Developed by
FHWA Multi-Regional Training and Certification Task Group
August 1999

IN MEMORIAM



Mr. Robert W. Rahn, Laboratory Testing Manager, Materials and Tests Division, Indiana Department of Transportation, passed away October 11, 1998.

Mr. Rahn worked for INDOT for 37 years in both technical and supervisory positions. He was a graduate of Indiana University-Purdue University (IUPUI) at Indianapolis. Mr. Rahn was active in many committees, including the Purdue/INDOT/FHWA Joint Highway Research Program and represented INDOT on the IUPUI, School of Construction Technology Business/Industry Advisory Board. In addition to his duties at INDOT, Mr. Rahn was a guest lecturer and a part-time instructor at IUPUI. Mr. Rahn was scheduled to become a full-time instructor's position at IUPUI following his scheduled retirement from INDOT.

Even though we on the Soils Team were privileged to work with Bob for only a short period, his contributions had a significant impact on the quality and quantity of information included in the soils training package. His expertise and personal drive brought a level of professionalism to this material that greatly enhanced the value of the final publication. We will remember Bob, not only for his technical knowledge and experience, but for his human side as well. He was quick-witted and highly supportive of both the project and the individual team members.

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Special thanks to Paul Stegemann, Physical Testing Supervisor, MODOT, for his assistance in the Pilot Course and the review of these materials.

Also special thanks to the Louisiana Department of Transportation and Development, Louisiana Transportation Research Center, Technology Transfer and Training, for allowing the reprint of excerpts from their training course, *Density Testing for Embankment and Base Course*.

Logo designed by C. Gordon Smith, Technology Transfer and Training Manager, Louisiana Transportation Research Center, Louisiana Department of Transportation and Development.

PREFACE

The Code of Federal Regulations, Part 637, requires all personnel performing sampling and testing for control or acceptance (QC/QA) to be “qualified” after June 29, 2000. This means that before this date, each state highway department must have an approved program in place to evaluate individuals who will perform such sampling and testing. This manual was developed under the sponsorship of the Federal Highway Administration (FHWA) to assist states in meeting this requirement. The training packages in this manual were developed by representatives from state highway departments and the FHWA. The individual procedures included in this manual were selected by representatives of state highway agencies, the FHWA, academia, and the national transportation industry at the 1997 Multiregional Training and Certification Conference. The group selected the test methods (AASHTO and ASTM) included in this manual based on their knowledge of tests used in the transportation industry. The use of AASHTO and ASTM procedures also supports the reciprocity of the personnel qualification programs between different state highway agencies. States are free to use these materials as they wish. They can be used as presented, modified to match the agency’s own testing procedures, expanded to include state specifications, sampling procedures, documentation, etc. Each state should use their own standard forms for the documentation of test results. No forms are provided with this manual. The prerequisites listed for each procedure are recommendations and may be changed by the user.

This manual contains training materials for the area of soils. The training materials are written to be programmed interactive texts, in which the student studies them at the individual’s own pace, or to be used as texts for instructor guided classes. The packages are designed to provide the student with a background in the construction-related characteristics and properties of the material, testing theory, and practical testing guidelines. These training materials will provide the student with basic information about each test protocol. They should be used in conjunction with laboratory or field experience in the performance of the procedures. The manual will assist in preparing for state qualification/certification by developing the skills needed to pass both written and performance evaluations. The student should read the preface and the section “To the Student” for specific information about the training packages in that material area.

Students are to use the mathematical rounding rules for each state agency in performing calculations for qualification testing. The rounding used in this manual reflects that of the AASHTO procedure.

A separate CD-ROM containing performance evaluations and example written exams is also available for each state. The written exams are based on the information contained in each study package. The performance evaluations provide a standardized grading system to evaluate the technician’s mastery of the procedure. This CD-ROM will be made available to state training officers for their use in developing a testing program for QC/QA personnel.

TO THE STUDENT

This training manual is designed to provide the student with comprehensive general information about soils and the testing of these materials for construction purposes.

The manual is organized into sections based on AASHTO or ASTM tests. The training packages are in the presentational order recommended by the M-TRAC team. Some of these procedures are prerequisites for others, because of their complexity or because it is usually necessary to perform one procedure before another in order to obtain test results.

The individual training packages follow the same format throughout the manual. Each individual procedure is organized in the following order:

- ❖ Title Page
- ❖ Prerequisites
- ❖ Table of Contents
- ❖ Basic Information About the Soil Property Being Tested
- ❖ Summary of Procedure - a brief description of how to perform the test
- ❖ Common Procedural Errors
- ❖ Typical Test Results
- ❖ Test Methodology - a complete rewrite of the procedure in simple terms, including any steps not completely spelled out in the original test procedure. This section may include photos, diagrams, etc. as training aids. The section is organized in a standard outline format.
- ❖ Glossary - terms relating specifically to the procedure

The training packages can be used to study at your own pace to learn basic information about construction properties of the material and how to perform the procedures or as a reference text for an instructor-guided class. The training package will serve as a reference as you progress with your study. This manual will assist you in preparing to pass the written examinations and performance evaluations that are a part of this course. These materials will be of benefit to you in becoming a qualified/certified technician or inspector.

It is the intent of the FHWA to maintain these training materials current to any changes that occur in these testing protocols following this publication date. For information on the latest edition of these training materials, have your training office contact the FHWA Midwest Resource Center.

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TOPIC

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INSTRUCTOR'S GUIDE



Developed
by
FHWA Multi-Regional Soils & Certification Group
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PREFACE

This guide is designed to assist training personnel, highway engineers, and technicians in presenting the material encompassed by this course. The material should be presented as a combination of instruction, demonstration, and hands-on practice. The instructional sessions should be followed by a period of job experience in which the student has the opportunity to become proficient in the performance of these tests. Written exams and performance evaluations should not be administered until students have had adequate time for material mastery.

The material contained in this training course is specific to AASHTO sampling and testing protocols and should be used as a basis for establishing a qualification program. When used as published, this program meets the intent of the training requirements of CFR, Part 637. This manual, used as designed, will meet FHWA requirements. Any additions based on a state's individual requirements should be made as a supplement to the basic training materials. Changes to these published procedures may negate FHWA approval of this course.

RECIPROCITY

It is recommended that states teach these basic AASHTO procedures first, supplementing the standard materials with the state's policies and unique procedures. Trainees would then be qualified for the AASHTO procedures, enabling them to present their credentials for reciprocal qualification in other states.

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FORMAL INSTRUCTION

PRESENTATIONAL ORDER

The course developers recommend that the materials be presented in the following order:

- ◆ Soils: Their Origins and Their Existence
- ◆ Why We Test Soils
- ◆ ASTM D2487, Visual Classification
- ◆ ASTM D3665, Random Sampling
- ◆ T-248, Reducing Samples
- ◆ T-87, Dry Preparation of Soils
- ◆ T-100, Specific Gravity
- ◆ T-88, Particle Size Analysis
- ◆ T-89/90, Atterberg Limits
- ◆ Moisture/Density Theory, Introduction to T-99
- ◆ T-99, Moisture-Density
- ◆ T-191, Sand-Cone Method
- ◆ T-272, Family of Curves
- ◆ T-238/T-239, Nuclear Moisture/Density
- ◆ D2488, Unified Classification

This sequence leads the student logically from the simplest procedures to the more complex, in the same basic progression typically used for soil sample evaluations.

CUSTOMIZATION

Each state should customize its presentations to reflect typical soil and soil-aggregate materials which occur within the state's geography. Additionally, any unique geomorphological or geological characteristics within state boundaries should be included. The presentation on the origins and existence of soils should be followed by examples from state geology, soil maps, soil/vegetation relationships, etc. The typical test results, common testing errors, and unique problems of each test procedure should also be modified to reflect local/state soil engineering characteristics. No reporting forms are included in these materials. State presenters should use their own standard forms for the documentation of test results. The state should not rewrite the published materials, but expand them to include local soil characteristics. Changes to these published procedures may negate FHWA approval of this course.

Differences between state highway agency testing procedures and the AASHTO procedures should also be noted. If state procedures differ from the AASHTO procedures, the state will need to document that the state procedure will yield the same test results as that of the AASHTO procedure.

LECTURE SESSIONS

The information contained in these materials can be used in a formal classroom, in front of small workgroups, or even one-on-one. The slide presentations are, of course, designed for use in a formal class. The student text can be used as modules or as a complete manual. It is to be noted, that the Pilot Program established that the complete course is too long and too detailed to be effectively presented to beginners in one session. For most effective learning, students should be close to the same level of experience and competency. It is recommended that the course be divided into logical blocks for extended presentations, which can be followed by periods of on-the-job training.

It is critical that the initial presentation include:

- ◆ the reasons for performing the test
- ◆ the importance of standardized testing techniques and precision in obtaining results
- ◆ how the test fits in with other tests to determine the engineering characteristics of the soil
- ◆ specifications regarding the test result and the reasons for these values
- ◆ differences between the state procedure and the AASHTO procedure
- ◆ critical testing steps and commonplace errors
- ◆ documentation and reporting of test results

TECHNICAL DEMONSTRATIONS

As part of the instructional process, each lecture session should be closely followed by a practical demonstration of the test procedure. This demonstration should be conducted by a technical trainer who is extremely proficient at the intricacies of the procedure. This section of the training session is an opportunity for students to see the procedure performed correctly. The demonstration should include an on-going discussion of proper testing techniques which are critical to obtaining correct results. Commonly used, but incorrect techniques or shortcuts, should also be stressed, with the errors caused by such mistakes highlighted. Time must be allowed for technical questions and answers during the demonstrations. Student involvement must be encouraged. The demonstration must be made to groups small enough that the testing techniques are clearly visible to each student and the potential for discussion is maximized.

HANDS-ON PRACTICE

Following the demonstration, each student should perform the test under the supervision of an experienced technician. One soil sample should be used for all testing so that at the end of the entire program, the student will have performed a complete evaluation of a specific material. This will provide continuity leading to a progressive understanding of soil behavior, how each test contributes to the complete analysis of the soil, and how the basic engineering properties of a soil are determined. The use of a single material also allows the instructor to compare student results to predetermined results for that sample so that the student knows how well the results compare to the standard.

CAUTION

The use of teams during hands-on training sessions, while expedient, is not to be encouraged. When more than one person is responsible for the result, the student who is more proficient than the other team members will tend to dominate the practice session. The less proficient students will look to the more experienced teammate to take responsibility for team results, thus negating the intent of the practice session.

APPENDIX

The lecture materials (computer-generated slides) are in the following formats:

Soils: Their Origin and Their Existence	Corel Presentations - 8
Why We Test Soils	Corel Presentations - 8
AASHTO T 87	
Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Test	
	Corel Presentations - 8
AASHTO T 88	
Particle Size Analysis of Soils	Power-Point
AASHTO T 89	
Determining the Liquid Limits of Soil	Corel Presentations - 8
AASHTO T 90	
Determining the Plastic Limit and Plasticity Index of Soils	
	Corel Presentations - 8
AASHTO T 99	
The Moisture-Density Relations of Soils Using a 2.5 kg Rammer and a 305 mm Drop ..	
	Corel Presentations - 8
AASHTO T 100	
Specific Gravity of Soils	Power Point
AASHTO T 191	
Density of Soil In-Place by the Sand-Cone Method	Power Point
AASHTO T 238	
Density of Soil and Soil-Aggregate In-Place by Nuclear Method (Shallow Depth)	
	Corel Presentations - 8
AASHTO T 239	
Moisture Content of Soil and Soil-Aggregate In-Place by Nuclear Method	
(Shallow Depth)	Corel Presentations - 8
AASHTO T 248	
Reducing Field Samples of Aggregate to Testing Size	
	Corel Presentations - 8
AASHTO T 265	
Oven Dry Moisture Test	Corel Presentations - 8
AASHTO T 272	
Family of Curves----One Point Method	Power Point
ASTM D 2487	
Unified Classification	Power Point
ASTM D 2488	
Visual (Textural Properties)	Power Point
ASTM D 3665	
Practice for Random Sampling	Power Point

These teaching aids are provided for you to use or modify as needed.

SOILS

Their Origin and Their Existence



Developed by
FHWA Multi-regional Soils Training & Certification Group

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PREFACE

The volume of knowledge about geology (the study of the earth), geomorphology (study of the physical forms of the earth), and pedology (study of soils) requires that many generalizations be made in this text. This course is designed to provide the student with broad knowledge about soil formation and soil characteristics. It will show how these characteristics can predict the performance of a soil for a specific engineering purpose. The information in this course will enable the technician to exercise improved evaluation techniques when analyzing the results of soils testing. This information will assist geotechnical personnel in analyzing test results as part of subgrade/foundation studies to determine the appropriate use of soils for highway construction. Knowledge of geology and soil mechanics (how soils behave) will enable the technician to predict the response of a specific soil to a specific test and to recognize test results which do not conform to normalcy.

Books on geology, soil mechanics and related subjects are readily available from libraries, book

stores, professional societies, and government agencies. The authors of this training course encourage the technician to use these resources to supplement this material and to continue the study of soils.

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INTRODUCTION

Humans have walked upon soil without much thought since earliest times. In many instances, soil has been treated with disdain. Many people consider soil just to be ordinary "dirt." They curse it when their vehicle becomes stuck in the mud. Mothers become upset when their children play in it and become "dirty." This mind set has spilled over into our language to the extent "dirty" and "soiled" have become synonymous with such words as stained, foul, filthy, nasty, sordid, and other derogatory words. We hear it daily in such phrases as "dirty politics" or "soiled reputation." We are bombarded constantly by the advertising industry trumpeting the value of each soap product in removing the dirt from our hands, hair, clothes, floors, and cars as though they are trying to eradicate soil from the face of the earth.

In reality, soil comprises much of the earth's surface and without this complex mix of mineral fragments, organic material, moisture, and gases, as well as the biological and chemical processes resulting from it, life as we know it would not exist on our planet. Soil is the upper layer of the earth's crust. Soil provides us with a continuous supply of food, lumber for homes, pigment for artists, medicine for health problems, clay for bricks and fine china. It contains our groundwater, provides support and construction material for our buildings, roads and airports, and other benefits unlimited in number.

Soil is a constantly changing substance. The beginning of organized study of this natural material has been lost in antiquity. However, we do know that humans have practiced agriculture for thousands of years. The knowledge gained from farming activities has led directly to extensive soil management techniques and practices. We also know that society has been involved in constructing sophisticated foundations and roadways with soils at least since Roman times. These construction activities have led to what is commonly known as soil mechanics (the study of soil behavior). Studies of the earth's crust have been brought about by various needs and interests. These studies have been used by different disciplines including, soil scientists, soil engineers, agricultural engineers, geologists, engineering geologists, architects, architectural engineers, geotechnical engineers, and geophysicists. All these fields of technology have been created for different purposes; however, they are all tied together by this one material, soil. There is much overlap in these disciplines. They all use information from soil samples tested under field and laboratory conditions.

As technicians we need to have an understanding, not only of the technical world of field and laboratory testing of soils, but also of the origin and nature of these materials. This knowledge will enable the technician to know where and how to select meaningful samples, so that the results of any test become more than just a number. A background in soil study will make test results take on real value. The technician will be able to correlate them to a particular soil and its condition and origin to rapidly determine if a result is reasonable (therefore, valid) for a particular soil.

Anyone without a background in soils may believe soils, like other materials used in construction, behave in a stable manner and that simple, routine tests can accurately predict the material's performance. A test result is just the beginning in the evaluation of a soil sample. Judgement is an absolute necessity in this process. Each soil, like human fingerprints, is unique. To understand the uniqueness of soils, let us start with their beginnings.

GEOLOGY - SHAPING THE EARTH'S SURFACE

The origin and development of the earth is a subject of much speculation and scientific investigation. Whether Earth is a result of the "Big Bang" or some other cosmic cataclysm, the end result has been the creation of a unique planetary body. The earth, 4.5 billion years old, is not a dead mass of rock whirling through space. It is a dynamic system comprised of various interrelated subsystems for which scientists are just beginning to develop an understanding.

STRUCTURE

The earth is an imperfect spheroid approximately 12 875 km (8000 mi) in diameter rotating on its axis, west to east, generating surface speeds at the equator in excess of 1 600 km (1000 mi) per hour. Chemical differentiation due to the internal heat of the earth caused by friction from compression and radioactive decay has resulted in identifiable layering. Moving from the surface toward the center, the earth is composed of a very thin crust, the mantle, and the core. During early stages of the planet's development, heavy elements, such as nickel and iron, sank to the earth's core while lighter elements such as aluminum, silicon, and oxygen migrated to the surface. This separation has resulted in materials at the surface of continents having average specific gravities of approximately 2.65, while the specific gravity within the core may be as high as 15.

The earth's atmosphere and water were formed later than the planet. Not until green algae evolved did oxygen begin to accumulate. Green algae performed in early earth much the way plants add to the oxygen supply today by absorbing carbon dioxide and releasing oxygen. The planet's water supply came from the condensation of gases released through volcanic activity. This process still continues at a steady rate.

The earth's surface layer is composed of numerous plates of crustal material literally floating in mantle material, like large rafts, much as wood floats on water. This is known as the principle of isostasy. These crustal materials are of two types. Basaltic material approximately 6 km (4 mi) thick lies beneath the oceans. The continental crust generally consists of granitic material an average of 35 km (22 mi) thick. Where mountains, high plateaus, and major sedimentary basins have formed, these continental rock masses may be as much as 70 km (40 mi) thick.

PLATE TECTONICS

The configuration, composition, and structure of the earth are best explained by a phenomenon termed plate tectonics. The lighter and rigid crustal material floating in the hot, melted upper layer of the mantle allows the crust to tear and become segmented into large irregular plates, (Figure 1). These plates, adrift in a sea of molten magma, move relative to one another at measurable rates of 10 - 100 mm/yr (0.4 - 4 in./yr). The continents, imbedded in these plates, move in unison giving rise to the term continental drift. Crustal plates exhibit three different types of boundaries:

- ❖ Shear Boundaries - These occur when plates slide by one another displacing crustal material along the shear (strike-slip fault). A well known example of this feature is the San Andreas Fault of California.
- ❖ Subduction Zones - These occur when plates collide forcing the margin of one plate under the other. This process drags crustal material downward where it is melted and returned to the crust as magma. Much of the volcanic activity around the Pacific Rim (commonly known as the Ring of Fire) is related to this process.
- ❖ Spreading Boundaries - These are areas where molten rock from depth rises and fills rifts left as plates separate. This occurs at mid-ocean ridges. As this molten rock filling cools and crystallizes new ocean crustal rock is formed. The best known feature of this type is the Mid-Atlantic Ridge.

The rising of molten materials at the mid-ocean ridges and the down-surfing of the crustal material in the zones of subduction at the plates margins are part of a cycle which continually replenishes crustal rock. (Refer to Figure 2.) It is thought that due to temperature differences between the layers of the earth, thermal convection cells form with molten material rising from depth into the rifts along zones of separation. As these molten materials cool, they form new ocean crustal rock which is then pulled across the ocean floor and down into the subduction zones to be melted again. These new melts are then refined by heat and pressure. Due to the lower density, the granitic portions become continental crust by being ejected as lava during volcanic action or injected as batholiths (or similar features).

COMPOSITION

Igneous rocks are those formed by the cooling of magmas (complex siliceous solutions) which have risen from deep within the earth. Igneous rocks are of two basic types, intrusive and extrusive.

- ❖ Intrusive (Plutonic) - These are granitic rocks which make up the greater part of large intrusions such as batholiths. They are coarse grained as a result of being crystallized at depth while cooling slowly.
- ❖ Extrusive (Volcanic) - These are basaltic rocks which occur primarily as lava flows. They are fine grained to glassy due to the very rapid cooling and crystallization at the crust's surface.

Granite has a silica content of approximately 70%, while basalt contains approximately 50%. (Silica is what is commonly termed quartz $[\text{SiO}_2]$). Therefore, silicate mineral rocks are the building blocks of the planet. Because silica is highly resistant to weathering, it has a direct bearing on the development of land forms. This resistance to weathering also makes silica a major component of soils.

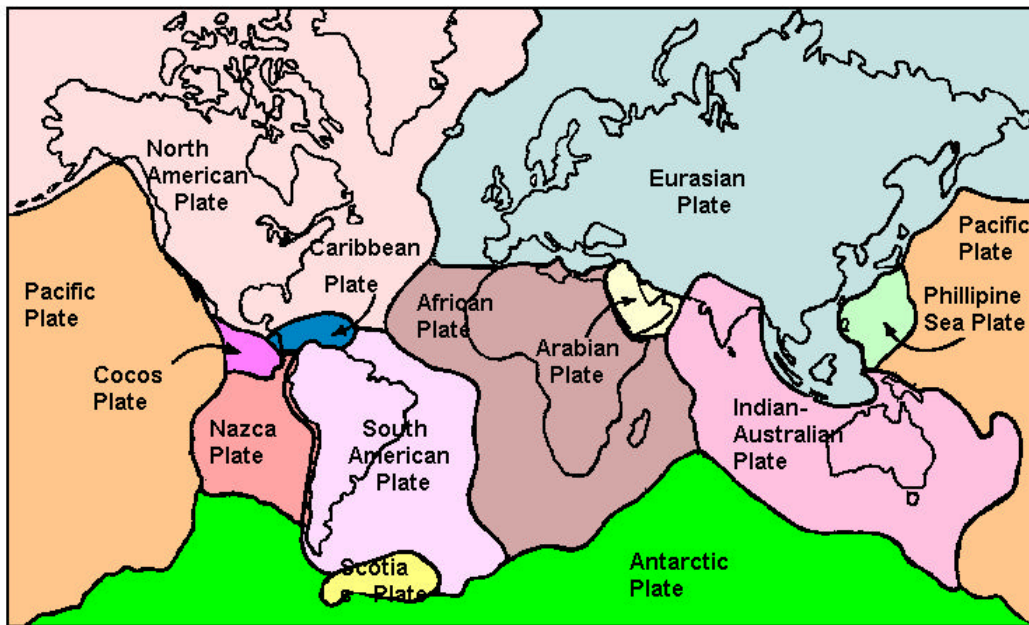


Figure 1
Plate Tectonics

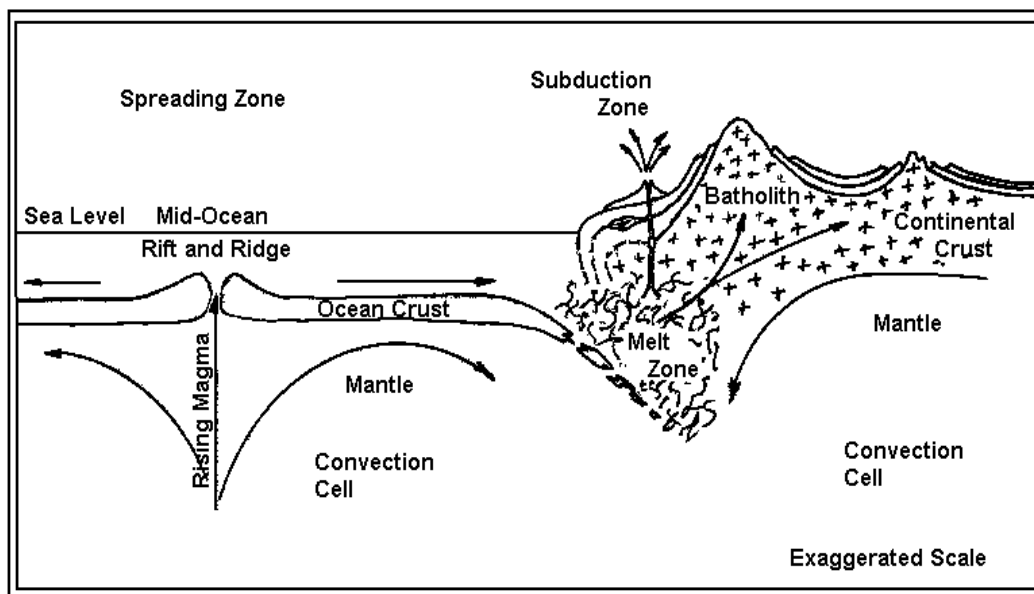


Figure 2
Idealized Cross Section of Plate Tectonics

PHYSIOGRAPHY

Plate tectonics create tremendous forces within the rocks of the earth's crust. As these plates collide, slide by, or override one another, huge upwellings of molten rock occur, mountain ranges rise, and significant crustal tears are created. Worldwide, the two dominant topographic features are the ocean basins and continents. The maximum relief between Mt. Everest (Himalayan Mountains), the highest continental elevation, and the deepest ocean trough (Philippine Deep) is approximately 19 km (12 mi). This, however, is a very small distance compared to the radius of the planet. Most relief is of very small magnitude and many areas of the continents are virtually flat. Exposure of the continental surfaces over long periods of geologic time to the deforming forces of plate tectonics and the ravages of climate have produced the surface that we see in our daily activities.

PHYSIOGRAPHY OF THE CONTINENTAL UNITED STATES

The continental United States is mostly a broad central plain lying between ranges of mountains to the west and east. These three major divisions are readily recognizable from geology, topography, climate, and biodiversity. Traveling east or west, going into or out of these areas, the changes are usually rather abrupt.

The central plains are comprised primarily of the high plains called the Great Plains and the Central Lowlands (high-grass prairies). Toward the south these areas transition into the coastal plain along the Gulf Coast. These plains and prairie areas may locally exhibit considerable relief from erosion; however, they are essentially flat with horizontally layered formations. Within this vast region there are some anomalies of limited area which disrupt its "flatness." These include the Arbuckle, Ouachita, and Ozark mountains of Oklahoma and Arkansas.

The Appalachian System, which forms the eastern border of the central plain, is a continuous series of small mountain ranges of parallel ridges and valleys created by severely folded strata which has also been heavily faulted. Much of the faulting is characterized by formations having been pushed up and over adjacent rocks (thrust faulting) indicating significant compression and resulting crustal shortening.

West of the central plains, the approximately 1600 km (1000 mi) wide cordilleran system rises much higher and with greater expanse than the Appalachian system of mountains to the east. These features, essentially parallel to the Pacific coast, result from a complex history of intrusive batholiths, extrusive lava flows, and folding with extensive faulting. This mountain region includes the Rocky Mountains, Cascade-Sierra Nevada Mountains, and the coast ranges near the Pacific Ocean. Between these individual mountain ranges are broad plateaus including the Colorado Plateau west of the southern Rockies and the Columbia Plateau between the Rockies and Cascades. This mountainous area is associated with the Pacific rim volcanic activity commonly referred to as the "Ring of Fire." It is also at the boundary of the Pacific and North American tectonic plates.

Within these three major physiographic regions, there are smaller areas with readily recognizable differences in landform, vegetation (Figure 3), and climate. Some exhibit deep canyons with high cliffs and streams with turbulent currents. Some are characterized by gentle slopes, rounded hills, and slow moving water. Others are essentially flat for extended

distances. Each of these subdivisions has its own unique characteristics and similarities which allow their separation into geologically-based provinces (Figure 4).

The type of rock, the structure, landforms, erosional patterns, and soil types are all related to physiography and the resulting topography. Both are indicators of geological history. (Refer to Figure 5.) Studying this history provides the knowledge to comprehend the ever evolving crust of the earth. The soil sample in the testing laboratory relates directly to this history. The following are some basic concepts to be considered when interpreting landscapes.

- ❖ What we see at this moment has resulted from modifications to a former surface over geologic time.
- ❖ The same processes and gravitational laws that are in operation today have influenced landscape development throughout geologic time.
- ❖ Geology is a dominant factor in controlling the landscape which evolves in an area and is reflected in it.
- ❖ Each chemical and physical process develops its own characteristic landform.
- ❖ As erosion occurs, a sequence of landforms develops which are distinctive of their stage of development; either youth, maturity, or old age.
- ❖ Evolution of crustal surface is more complex than simple.
- ❖ Climate is a direct, significant contributor to surface evolution. Landscape, vegetation, and soils are dependent on this factor.
- ❖ Everything in nature tends to develop in cycles. Erosional cycle, hydrologic cycle, soil cycle, rock cycle, and life cycle are all examples of nature forming, changing state, reclaiming, and reforming.
- ❖ What we see as the crust's surface at the moment is the beginning of a new landscape.

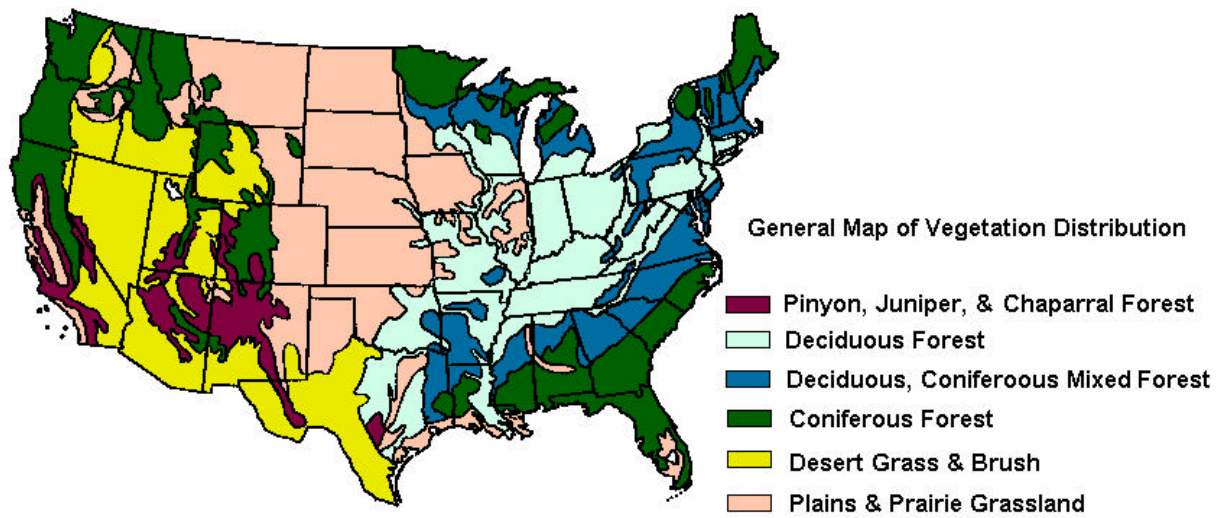


Figure 3
Vegetation Distribution

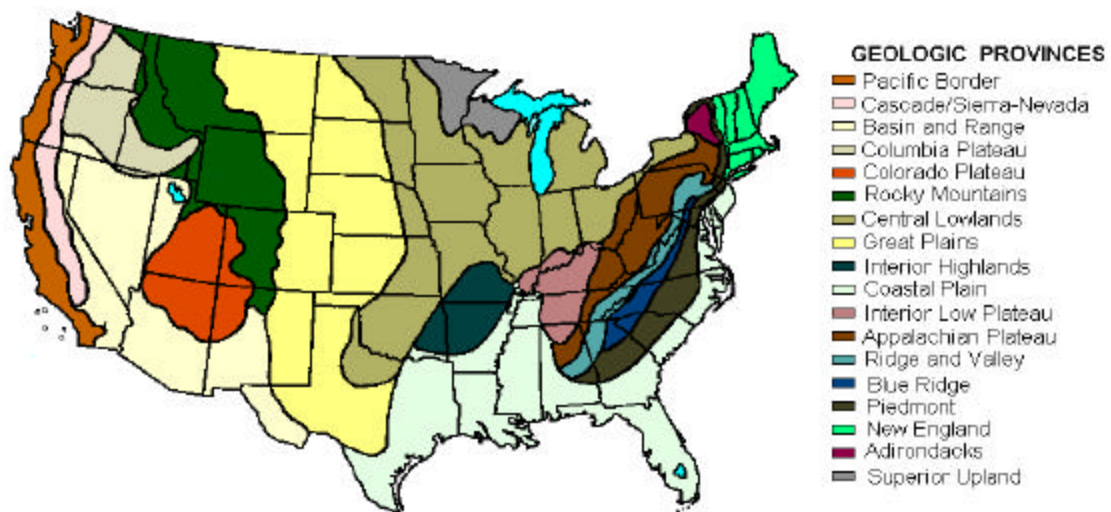
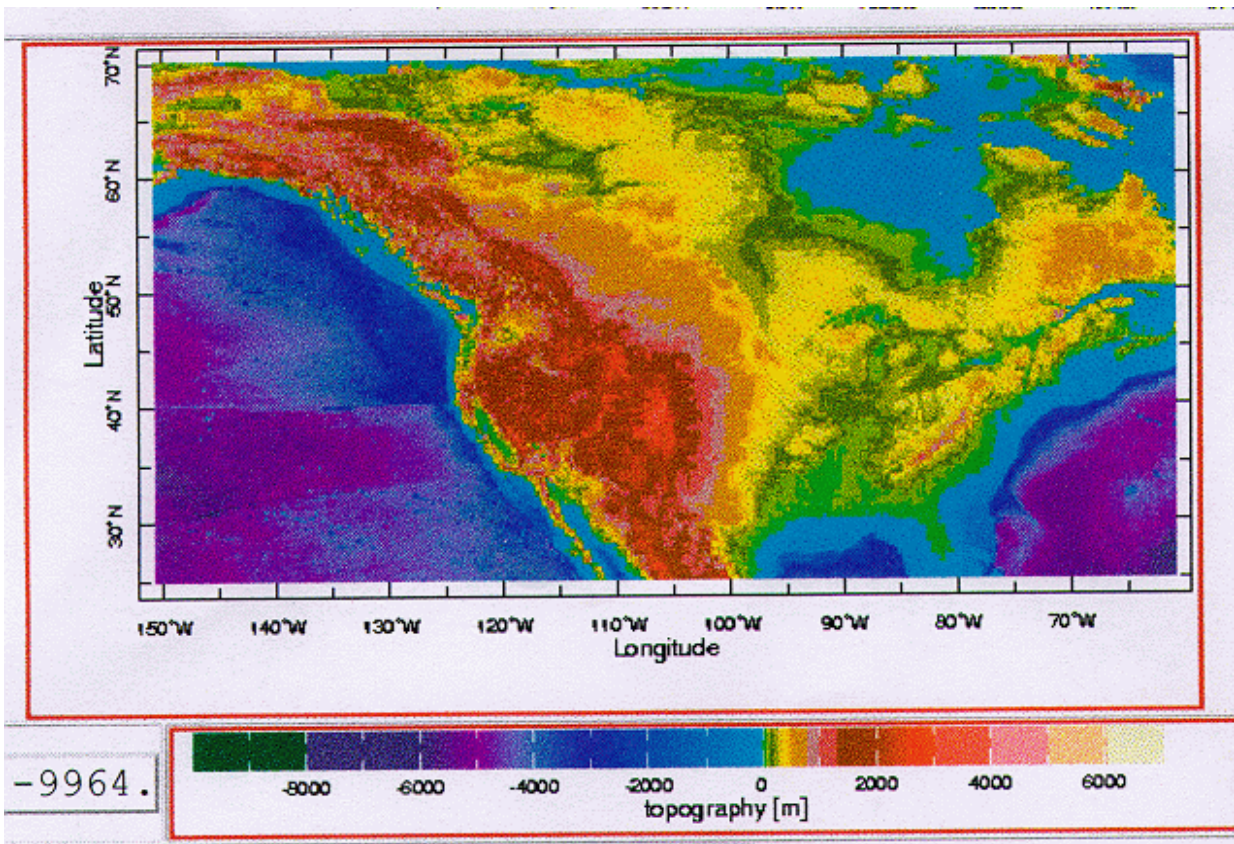


Figure 4
Geologic Provinces



Topographic Map of the United States and Canada
Figure 5

SOIL DEVELOPMENT

Each facet of society develops its own definition of soil depending on its interests and needs. Therefore, many different definitions have resulted. To the general public, soil is simply dirt. Webster's Dictionary defines soil as "the upper layer of earth that may be dug or plowed: the loose surface material of the earth in which plants grow." The Natural Resources Conservation Service, USDA, defines soil as "a three-dimensional body at the earth's surface. It is capable of supporting plants and has properties resulting from the integrated effect of climate and living matter acting on earthy parent material, as conditioned by relief over periods of time." ASTM D 653 defines soils as "(earth), sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter." This definition is generally accepted by geotechnical personnel involved in highway construction.

DEGRADATION

Soil creation begins with the breakup of rock mass. Rock masses are reduced to particle size (clastic state) by a complex phenomenon termed degradation. Degradation can be divided into three (3) major processes, which in nature overlap to varying degrees. These processes are weathering, mass wasting and erosion.

WEATHERING

Weathering is a complex of processes involving physical, chemical, and biological activities leading to the disintegration of mass rock. Weathering converts rock masses into soil.

Physical weathering is caused by the action of agents such as wind, water, freeze/thaw cycles, landslides, and earthquakes. It breaks particles from the parent bedrock. As these particles are moved by nature, their shapes are changed and they become increasingly smaller. Materials generated directly by physical weathering are commonly referred to as granular. These particles frequently continue to bear some characteristics of the parent rock.

Chemical weathering causes a complete change in the chemical and physical properties of the parent material. When water flows over and through rocks, some of the minerals are leached. These minerals, once precipitated, form new particles composed of mineral crystals which no longer have the characteristics of the parent rock. Agents of chemical weathering include oxidation, reduction, hydration, solution, and carbonization.

Biological weathering is a combination of physical and chemical breakdowns. Physical deterioration is primarily caused by roots of vegetation, although animal activity may also play a minor role. Chemical change is caused by organic acids and carbon dioxide supplied by plants. Bacterial activity also contributes to chemical change.

Mass Wasting

Mass wasting is the movement of rock debris down slope primarily under the direct influence of gravity. Water may be present to act as a lubricant and minor carrier, but is not necessary to the process. The common terms talus and colluvium are applied to rock fragments that accumulate in this process of degradation.

Erosion

Erosion, like the term soil, has been defined to mean different things to different disciplines. In all these definitions, there is usually an implication of transport. Regardless of the definition, there is a segment of this process that is degradation. Whether the transportation mechanism is wind, water, ice, or gravity, there is always a gradual breakdown of rock particles into ever smaller pieces. The grinding, bumping, and bouncing that takes place in transit are important in the process of degradation. Erosion can take place without weathering.

TRANSPORTATION

The results of degradation are rock fragments and materials dissolved in water. The resulting detritus is usually swept away by physical agents to become clastic sediments. The material in solution is carried away, ultimately to be added to the water of lakes and oceans. These dissolved materials then become deposits of an entirely different nature.

Is it difficult to visualize a large boulder the size of a house breaking loose from the Rocky Mountain batholith at the continental divide and moving down slope, breaking up with the pieces becoming smaller and smaller until some of the particles enter the drainage system to end up in the Mississippi River delta as sand, silt and clay? This is the continuing process that has been taking place for the eons of geologic time.

As the rock mass is reduced to a clastic state through degradation, nature can move the smaller particles more readily. This transportation effort is accomplished by wind, water, ice, and gravity working and reworking particles as they progress persistently to lower grade. Long periods of geologic time are required for these results. The transportation of particles is primarily accomplished by the following actions (Figure 6), alone or in combination.

- ❖ **Traction** - the pushing, dragging or rolling of particles too large to be lifted and carried in the transport medium.
- ❖ **Saltation** - the bouncing of particles that are too large to be held in suspension.
- ❖ **Suspension** - the lifting of particles into the transporting medium.
- ❖ **Solution** - the incorporation of material into water in which the material actually becomes a chemical component of the moving liquid.

MAJOR PROCESSES OF DEGRADATION AND TRANSPORTATION					
Agent	Assimilates Load of Weathered Material	Transport Method	Degradation During Transport	Resulting Features ¹	
Water Running Water Streams Sheet Floods Ground Water Waves & Currents Lakes Oceans Lagoons				Erosional	Depositional
	Hydraulic Action	Traction Suspension Saltation Solution	Abrasion (Physical) Corrosion (Chemical)	Stream Valleys Water Falls Mesas	Flood Plains Alluvial Fans Deltas
	Solution	Solution	Corrosion	Sink Holes Caves Karst Lakes	Stalactites Stalagmites Limestone
	Hydraulic Action	Traction Suspension Saltation Solution	Abrasion Corrosion	Sea Cliffs Tidal Channels Sea Caves	Beaches Off-Shore Bars Spits
Glaciers Continental Mountain	Scouring Plucking	Traction Suspension	Abrasion	Ice Scour Glacial Troughs Cirques	Moraines Eskers Erratics
Wind	Deflation	Traction Suspension Saltation	Abrasion	Hollows Ventifacts Desert Pavements	Sand Dunes Loess Sand Sheets
¹ Feature list is not all inclusive.					

Figure 6: Major Processes of Degradation and Transportation

Igneous Rock	- Those rocks formed by the cooling and hardening of molten magma from deeper areas of the earth. Molten material that is extruded onto the surface is known as lava. Granite and basalt are common igneous rocks.
Metamorphic Rock	- Those rocks formed by tremendous heat and pressure which alter the original character of the previously existing rock. Slate, marble and quartzite are common rocks of this group.
Sedimentary Rock	- Those rocks which are formed by either mechanical or chemical formation from degraded particles of other rock. These are rocks which have become hardened as a result of compression and/or cementation.

Chemical Formation: As rock decomposes, soluble minerals are leached by water and transported to other environments. Precipitation of these minerals from streams, springs, lakes, or oceans results in the formation of a group of rocks including limestone, chert, chalk, marl, salt, and gypsum.

Sedimentary Soil - These soils are unconsolidated materials which have resulted from the degradation of other rock. Subsequently, the rock fragments have been transported and deposited. Unique soils, across the nation, number in the thousands. Materials in this group are commonly referred to in terms of grain size and are important to the construction industry as gravel, sand, silt, and clay. Soils which are not transported are called **residual soils**.

Soils: Origin & Existence - 12

Note that gravity is not listed as a transporting force. Gravity actually does not transport particles, but is always pulling particles toward the center of the earth and is a great influence in the movement of particles regardless of the other forces involved. Gravity causes downhill flow. In conjunction with transporting actions, gravity becomes a powerful tool to "plane" a surface or feature, significantly modifying it by reshaping and lowering elevations. These transporting agents cannot maintain their energy and chemical balance indefinitely. As transporting power diminishes, base level is reached, temperature, pressure, or chemical conditions change, and transported materials drop out and become deposits.

DEPOSITION

The remains of mass rock are deposited in the lower areas (relative elevation) of the earth's crust resulting in the elevation of those areas being raised. This process of deposition, in addition to diastrophism (mountain building) and vulcanism (volcanic activity), prevents degradation and transportation from ultimately reducing the earth's land areas to base level where they would be covered with water.

These deposits (detritus resulting from exposure of rock mass to the atmosphere) are the materials that, given the proper conditions and time, become what is commonly called soil. They may also become the beginning of new rock mass. If they become cemented, metamorphosed and melted, they can return to the crust as igneous, metamorphic, sedimentary, or volcanic rock (Figure 7). The student should aware that this cycle does not always progress in a uniform, linear fashion to successful completion, but is interrupted and sidetracked in erratic and complex ways, with infinite variations.

Soil is the result of natural actions (Figure 6) on these masses of rock. These actions result in a heterogenous mix of mineral fragments, organic matter, air, and water. Soil may be soft or hard, porous or dense, loosely or weakly cemented. The colors of soil may cover the spectrum; however, soils usually exhibit some shade of gray, white, or yellow.

As batholiths (granitic mountain cores), volcanic lava flows, sandstones, limestones, and other rock mass disintegrate, the resulting fragments (soils) can be categorized in terms of their environment, location, and the agents that created them.

- ❖ **Aeolian** - These soils are the result of fragments being transported and deposited by wind. These soil particles are usually relatively small, since wind does not have sufficient sustained energy to move large pieces of rock.
- ❖ **Alluvial** - These soils have been transported and deposited by the forces of moving water. Depending on the volume and velocity of the water, particles ranging in size from huge boulders to microscopic clays are moved in the process of creating these soils. Alluvial soils usually show distinct depositional layering and a reduction in particle size as the distance from the source increases. These materials represent much of the land surface.

- ❖ **Colluvial** - These materials involve the bulk movement of rock debris downslope under the direct influence of gravity. Varying amounts of water may be available, but water is not the major moving agent. Huge boulders routinely move down slope, colliding and grinding until particles of varying sizes accumulate at the bottom of mountains.
- ❖ **Glacial** - During periods of glaciation, ice picks up massive quantities of abraded material and transports them long distances. As the glacial ice melts, it deposits this debris.
- ❖ **Organic** - A soil generally created under a vegetative cover and under conditions that allow the accumulation of plant residue. This name can be applied to organic materials accumulating in marshes or bogs or where humus has been incorporated in soils such as topsoils.
- ❖ **Residual** - Residual soil is created when rock particles are not transported, but remain in their weathered position. These soils are unique in that normally no stratification is present. Rock fragments are similar to those in the bedrock immediately below and increase in size from top downward rather than laterally.

Immediately after deposition, rock fragments themselves begin to change due to the same processes which degrade rock mass. The weathering process to which the original rock mass was subjected is the most significant factor in producing the detritus end product. The end product will not necessarily bear any resemblance to the original parent material. As geological time passes, the differences between the products of the original parent material become increasingly more pronounced. The same rock mass can supply rock fragments to arid and humid climates, but different weathering conditions will result in two entirely different products.

In discussing soils, there is much written on the effect of parent material on the soil. The term “parent material” is used to refer to two distinctly different phases of soil development. One is the rock mass that produced the clastic deposit. After it has been deposited, the clastic material then becomes the parent material for the weathered soil. Weathered soil is the material with which we normally deal. Weathered soil is the material on which and with which our infrastructure is built.

From this point forward in this text, soil will be the term used to identify the material produced from weathered clastic material. Clastic material will now be termed parent material. The characteristics of any soil at any point of time are determined by the following.

- ❖ the climate to which the parent material has been subjected since deposition
- ❖ the physical and chemical composition of the parent material
- ❖ the relief
- ❖ the geological time over which natural forces have acted
- ❖ the animal and vegetative life (externally and internally)

CLIMATE

Climate is probably the most important factor in creating soil. Water, temperature and wind are the elements of soil modification. Wind is the least important. Generally, moisture availability is the dominate force in the maturing of soils. Under arid conditions, soil building is slow. Soil development is primarily caused by the physical forces of temperature and wind, because low moisture availability retards chemical activity. Since evaporation exceeds rainfall in these areas, ground water with its dissolved minerals is slowly brought to the surface through capillary action. As these mineral laden waters reach the surface and evaporate, the chemicals are left as a residue. Calcium carbonates are the most common of these chemicals. Other minerals formed by this process are borax, gypsum, and salt. These materials create hard crusts at the surfaces of coarse textured soils in these climatic zones. Caliche, a common construction material found in the Southwest, is a product of this environment.

Conditions of high humidity and temperature promote rapidly maturing soils. High rainfall quickly weathers minerals in the soils and aids the downward movement of clay and colloids. Plant remains decompose rapidly; therefore, highly organic soils do not readily form from vegetative cover. Acids produced during decomposition of organic materials promote the development of clay minerals and the reduction of carbonates resulting in clayey soils high in aluminum and iron. These soils are evident in the subtropical and tropical climates.

Thus, rainfall and evaporation tend to control the evolution of soil types. A line can be drawn from south to north, starting at the Gulf of Mexico in east Texas and extending northward to the Canadian border near the east boundary of the states of North and South Dakota. This line separates the continental United States into two sections. To the west of this line, the country receives less than 25 inches of rainfall per year; to the east, it receives more than 25 inches of rainfall per year. Correspondingly, soils high in aluminum and iron exist to the east of the line and soils high in carbonates are found to the west, Figure 8.

An interesting and important fact about climates is that mountains tend to reproduce climates in vertical zones, the effect of increasing altitude being similar to increasing latitude. Thus, the climate that produces a tundra soil at the top of a western mountain is similar to the climate that produces a tundra soil in Alaska with both soils being very similar. In addition to rainfall, temperature is an important factor in soil development. Temperature regulates the chemical and bacterial activity of soils. High temperature usually is a catalyst for chemical modification. Conversely, cold temperatures result in a cessation of chemical activity, especially when the ground is frozen. Thus, subtropical and tropical soils have undergone complete chemical alteration. Soils of the frozen tundra are composed primarily of mechanically produced mineral fragments with minimal chemical alteration. Biological activity in the soils follows patterns similar to that of temperature. Bacteria actively consume organic material in regions with high temperature and humidity, producing soils with minimal humus. In colder climates, bacterial activity is significantly reduced, resulting in soils with high organic content where there is sufficient moisture to grow vegetative cover.

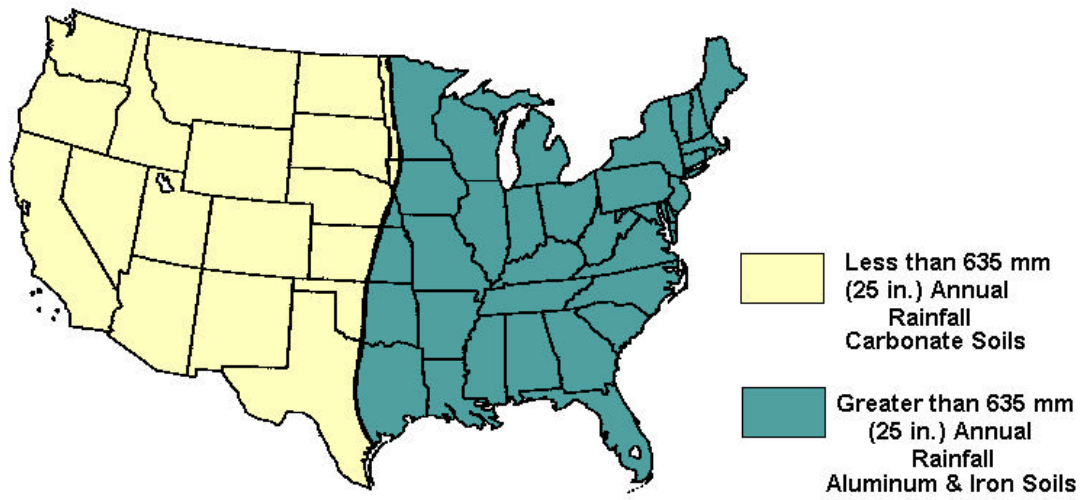


Figure 8
Soil Composition

PARENT MATERIAL (ROCK DETRITUS)

The parent material (residual or transported) is a passive contributor to the maturing soil mix. It only provides the minerals that are weathered into a particular soil. It is important to understand that parent material by itself does not determine the soil that will eventually develop. We have already seen that aridity and humidity are prime contributors in the development of soil types. The original size, shape, and mineral content of particles affect color, texture, permeability, mineralogy and erodibility of soils. Young, unweathered soils tend to be like the parent rock; however, with continued weathering that likeness eventually is lost. When rock detritus from the same or similar sources ends up in different climatic zones, the mineral fragments will eventually develop into soils of very different characteristics.

RELIEF

Relief influences soil formation by affecting internal and external drainage, erosion, deposition, temperature, and biological activities. Relief is a passive soil former. Where relief is great and slopes are steep, water drains rapidly resulting in a thin soil with less chemical activity, more erosion, and generally less biological influences. As slopes get flatter, soils retain more water, there is less erosion and life begins to increase. Flatlands with sufficient rainfall produce thick layers of soils, highly leached with thick layers of clay and minimal erosion. Soils that are formed in areas of greater relief are usually better drained and more highly oxidized with brown, yellow, or red colorations. Soils that form on flat bottom lands are very thick and poorly drained. Instead of oxidation, reduction takes place with less decay of vegetation allowing high percentages of organic to accumulate. These soils exhibit dark grey, blue, and black colorations. These soils are constantly water saturated and remain unstable.

Topography also influences soil formation. Slopes facing the warming and drying rays of the sun develop different soils than those on slopes facing away from the sun. Soils on slopes facing away from the sun retain more moisture at cooler temperatures and for longer periods of time.

GEOLOGIC TIME

Time is necessary for the development of soil. Without time passing, parent material equals soil. As time passes, all the soil forming agents take their toll on the parent material. The more time that passes, the more mature a soil becomes. The time required to produce a mature soil cannot be measured. It takes geologic time for nature to produce a mature soil in equilibrium. (Refer to Figure 9 for illustration of geological time scale.)

The last glaciers in what is today the continental United States retreated approximately 10,000 years ago. Since they melted, nature has been modifying the glacial till left behind. Most of those materials have not been completely weathered into their final form. There is no calendar schedule and so many factors are involved, including the possibility of cycle interruption, that any discussion of time required for soil development is speculative.

Era	Period	Epoch	Approximate Duration (Millions of Years)	Life Forms	Approximate Beginning (Millions of Years Ago)
Cenozoic	Quaternary	Holocene	10,000 years ago to present		

		Pleistocene	1.7		
			*****		1.7**
		Pliocene	9		
			*****		12**
		Miocene	14	Mankind	
			*****		26**
	Tertiary	Oligocene	12		
			*****		38**
Mesozoic		Eocene	16		
			*****		54**
		Paleocene	11		
			*****		65**
		Cretaceous	70	Placental Mammals	
			*****		135**
	Jurassic		55	Birds, Grasses & Cereals	
			*****		190**
		Triassic	35	Mammals & Flowering Plants	
			*****		225**
Carboniferous		Permian	55	Ginkgoes	
			*****		280**
		Pennsylvanian	40	Insects, Cycads & Conifers	
			*****		320**
		Mississippian	25	Reptiles & Primitive Gymnosperms	
			*****		345**
Paleozoic	Devonian		55	Amphibians & Vascular Plants	
			*****		400**
		Silurian	25		
			*****		425**
		Ordovician	75	Fishes & Mosses	
			*****		500**
		Cambrian	100		
			*****		600**
Precambrian	Proterozoic			Invertebrates & Marine Algae	
			3200		
	Archeozoic				
			*****		3800**

Figure 9
Geologic Time Scale

BIOLOGICAL (Fauna and Flora) ACTIVITY

Both plants and animals have significant impact on the development of soils and their ultimate character. Plants, animals, insects, bacteria, fungi, and other organisms, including humans, initiate physical, chemical, or a combination of these activities on soil. Bacteria, fungi, and other microorganism are primarily responsible for the decomposition of humus and the oxidation/reduction that affect the physical and chemical characteristics of soils. These kinds of activities are controlled by temperature. Chemical and physical action is strongest in warm, humid climates. The percent organic is commonly higher in poorly drained soils. Reduction activity is prevalent where water tables are high, resulting in gleyed soils. The better drained a soil is, the more oxidized it will be and the lower its organic content will be. The influence of animals, earthworms, burrowing animals, ants, etc., can also be important. They rework and aerate the soil, changing its texture and its chemistry. Plants bring calcium, magnesium, potassium, and other elements from lower horizons which are then added to the upper layers of soil as the plants drop leaves, die and decompose. This process changes the chemistry of soils, as well as physically altering soils through root action.

Humans and their activities have been profound in influencing soils and soil environments, especially in more recent times. Consider the impact of the following on the natural processes just discussed:

- | | | |
|------------------------|-----------------|--------------------------|
| ❖ cities | ❖ agriculture | ❖ cement/lime production |
| ❖ forest clear cutting | ❖ strip mining | ❖ aggregate production |
| ❖ dams | ❖ dredging | ❖ transportation systems |
| ❖ monoculture forests | ❖ levee systems | ❖ stream channelization |

Each of these modern activities is a method by which society is progressing, but each also gives birth to a new generation of stresses on the environmental factors of soil building. These activities change topography and biological activity, and may even be affecting climate. Time is impacted by the interruption of the natural cycles of soil building; parent material is being exposed and modified. All five soil building processes are being challenged. A major result is a significant shift in erosion throughout the United States. Prime illustrations are the "Dust Bowl" of the 1930's and dramatic coastal erosion caused by sediment starvation along the Gulf coast due to control of the Mississippi River.

SOIL PROFILE

In summary, soil, created and positioned by various geological processes, is constantly subjected to physical and chemical changes. These modifications are dependent on the soil forming factors present in the geographical area surrounding the soil itself. Through natural soil forming forces, what was once masses of rock, then boulders, then cobbles are now sands, silts, and clays which begin to take on significantly different characteristics resulting in what is scientifically termed a soil profile (Figure 10). Idealistically, a mature soil will exhibit three distinguishable major layers called horizons. In situ, however, soils exhibit highly variable soil profiles primarily depending on time and the intensity of soil forming processes. The three layers, which together may represent only the upper few meters of the earth's crust, are termed A Horizon, B Horizon, and C Horizon.

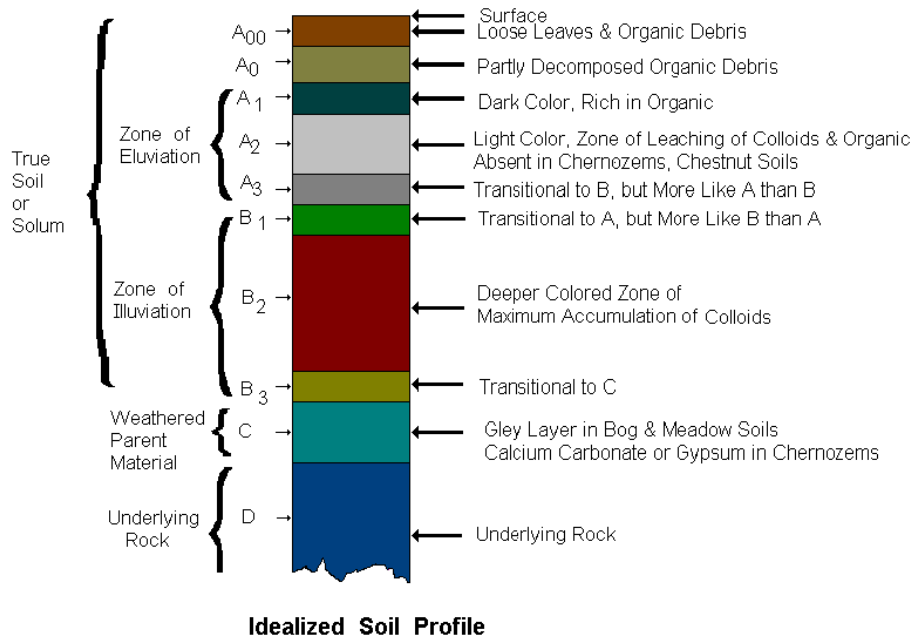
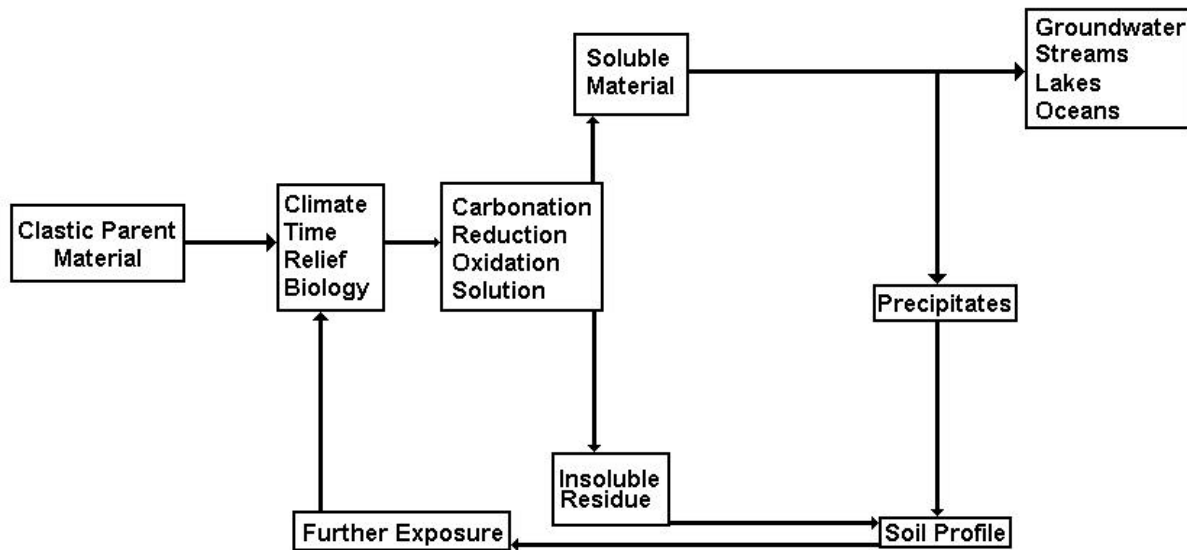


Figure 10

Soil Profile Development

- A Horizon -** The A horizon is the upper layer of soils immediately exposed to the most intense weathering. This is the material upon which we are dependent for our food supply and is of intense interest to the agricultural engineer. Where there is sufficient rainfall, the A horizon is a zone of higher organic content, usually leached of fine materials, and darker in color than the underlying layers. To geotechnical personnel, it is not considered good construction material due to its inherent instability.
- B Horizon -** This horizon immediately underlies a zone of transition separating the A and C horizons. Chemicals, minerals, and some organic material are leached from the upper A horizon percolating downward and collecting at this level. This process results in a higher clay/colloid content as well as a richer chemical mix than in the A horizon. These conditions also make soil materials from the B horizon suspect as useful in highway and foundation engineering.
- C Horizon -** This layer is separated from the B Horizon by another transitional zone that has neither the characteristics of the more weathered and complex B horizon nor the C horizon. The C horizon is the parent material from which both the A horizon and B horizon are formed. This horizon may be composed of a wide variety of materials from rock to reworked soft sediments. These parent materials are the least weathered of the soil profile and are, therefore, the most stable. The C horizon soils are of most interest to geotechnical personnel since they generally provide support for our buildings and transportation system. Also, most of the excavated soil materials used in the construction of earthen structures such as dams and embankments originate in this horizon.

The A and B horizons, in combination, compose the true soil (solum). These soils are derived from parent material which is represented by the C horizon. These solum materials, through the complex weathering processes previously discussed as soil building forces, are generally inferior in quality, questionable in usability, and generally unstable due to the higher clay/colloid contents, complex chemistry, and inclusion of organic contents. At a minimum, special design considerations must be employed to overcome the negative characteristics of the materials from these two horizons before they can be used in construction. Understanding of and attention to the soil profile provides insurance that data from soil mechanics tests from a particular horizon and soil will only be compared to the results from tests completed on that soil and horizon from other locations. Otherwise, meaningless assumptions and misguided judgements will be made. **Compositing soils or data horizontally or vertically can be disastrous when designing for soil use.**

Color

Color is a major characteristic in evaluating soils, soil profiles and keeping track of samples. Color is usually not considered an engineering parameter; however, engineering assessment can be well served by considering this factor. Natural colors recorded in the field during

sampling give the testing technician and the designer a distinct advantage when comparing and grouping soils. Color patterns such as banding, marbling, and mottling, are indicators of performance and should be recorded with other field data at the time a sample is retrieved. The intensity of soil color changes as moisture content varies; colors are readily destroyed by handling, drying and preparation that produces a homogenous blend of separate soil particles obliterating all of the original color or color patterns.

Color is an indicator of certain soil chemicals and mineral particles. Black to dark brown usually results from organic matter. Reds are due to the presence of iron in a well-drained soil that is highly oxidized resulting in hematite or siderite. Yellow-brown is also primarily a result of iron. This color is usually associated with the mineral limonite that occurs in soils with less drainage and less complete oxidation. Gray and blue soils result when soils are poorly drained. Yellow mottling sometimes occurs with these colors. The darker gray and blue (gleyed) soils are generally produced below permanent water tables; a result of reduction rather than oxidation.

All soil colors should be determined using the standard for soil surveys known as Munsell color charts. These charts are based on hue (rainbow color), value (lightness/darkness of color) and chroma (strength of hue). Color determination should be made only on damp soil. If the soil is excessively dry, it is appropriate to dampen the soil to accurately determine color.

SOIL IDENTIFICATION

After decades of intense observations by soil scientists and agricultural engineers, a system has been developed and refined based on soil characteristics and soil profiles that has universal acceptance and demonstrable use to the geotechnical efforts in transportation design and testing. This system, known as the U.S. Department of Agriculture Soil Classification, began in Russia during the 19th Century and is becoming widely accepted as the standard for identifying soils and grouping soils with like characteristics. The following quote from the PCA Soil Primer defines the value of this system to the transportation industry.

“Highway engineers found that this system and the resulting valuable soil information could be used in identifying soils, after which they could classify them for engineering purposes in their own work. Therefore, while the U.S. Department of Agriculture system is called a soil classification system for purposes of nomenclature and use by the agricultural engineer, it is used as a soil identification system by the highway engineer. This system is based on the fact that soils with the same weather (rainfall and temperature ranges), the same topography (hillside, hilltop, or valley) and the same drainage characteristics (water table height, speed of drainage, and so forth) will grow the same type of vegetation and be the same kind of soil. This is illustrated by the fact that the black wheat-belt soils of the West are the same as the black wheat-belt soils of Russia, Argentina, and other countries. The system is important basically because a subgrade of a particular soil series, horizon, and grain size will perform the same wherever it occurs since such important factors as rainfall, freezing, groundwater table, and capillarity of the soil are part of the identification system. In no other system in use are these important factors employed directly. The system's value and use can be extended widely when the engineering properties, such as load-carrying capacity, mud-pumping characteristics, and cement requirements for soil-cement, are determined for a particular soil. This is because soils of the same grain size, horizon, and series are the

same and will function the same wherever they occur. Therefore, a North Carolina engineer and a Texas engineer, after each has identified a soil in his or her own area by this system, could exchange accurate pavement design and performance data."

Note that the emphasis is on the use of the USDA system for soil identification, not classification as a replacement for AASHTO, ASTM or other engineering classification.

This system has been under continual refinement since its inception and in 1965 major changes were made in terminology. Therefore, when reviewing USDA soil information it is best to be familiar with terms pre-and post-1965. Information is readily available from the Natural Resources Conservation Service, USDA. The system is now divided into six (6) category levels; orders (11), suborders (53), great groups (261), subgroups (approximately 1900), families (approximately 6755), and series (greater than 17000) based on soil profile and soil characteristics. Each succeeding level further defines unique characteristics of that category. The eleven (11) orders generalized in Figure 10 are:

- Alfisol** - soils with aluminum and iron formed under primarily deciduous forests with a well-developed B Horizon containing leached clay
- Aridisol** - soils with calcium, gypsum or salt hardpan formed in arid climates
- Entisol** - soils of recent origin which exhibit minimal profile formation. This order includes tundra soils over permafrost that are serious engineering problems.
- Histosol** - bog soils containing peat and various organic materials. Severe engineering problems are associated with these soils.
- Inceptisol** - soils with indistinct horizons showing only beginning soil formation
- Mollisol** - soft, dark and crumbly A Horizon and the B Horizon exhibits clayey nature; well developed profile under grass vegetation
- Oxisol** - soil composed primarily of oxides, red B Horizon formed in tropical and subtropical climates; less than 0.02% of the soils in the United States fall into this group.
- Spodosol** - soils developed generally under coniferous forests on low clay parent material, most commonly resulting in an amorphous layer of aluminum and organic mixture.
- Ultisol** - soils with very well developed profile with a red to yellow B Horizon high in clay. Highly weathered, acid and developed under forest or grass.
- Vertisol** - nontypical profile showing vertical mixing due to high shrink/swell characteristics caused by high clay contents. Very serious engineering problems result.
- Andisols** - residual soil over volcanic material with poor profile development.

The lower subdivisions, including the soil series, are of the most interest to the geotechnical investigator. A soil series represents soils that are essentially the same with very similar profiles. Each series is divided into soil types by name. The Natural Resources Conservation Service has mapped almost the entire United States and published manuals of these soil

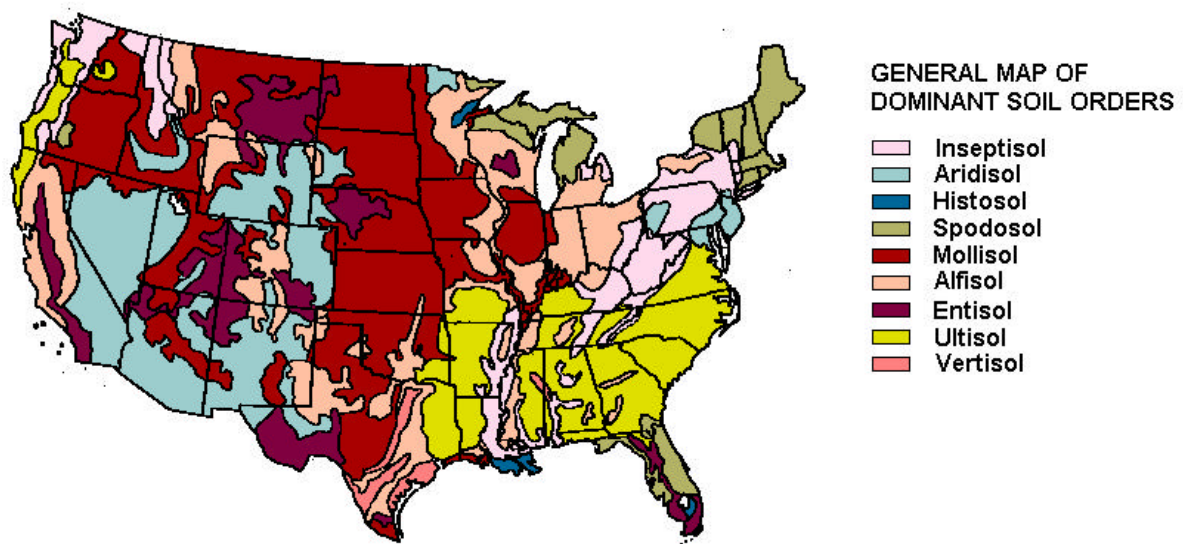


Figure 11
Dominant Soil Orders

surveys. The manuals have details for many professions from geology to agriculture to highway engineering. Each manual is specific to a county/parish and has two levels of mapping; a General Soil Map (Fig. 12) and soil types mapped on aerial photos (Fig. 13). This information is a significant assist to the technician or engineer in planning testing regimens and comparing results to in situ soils. Other engineering data provided by these manuals for geotechnical use in evaluating and using test results include:

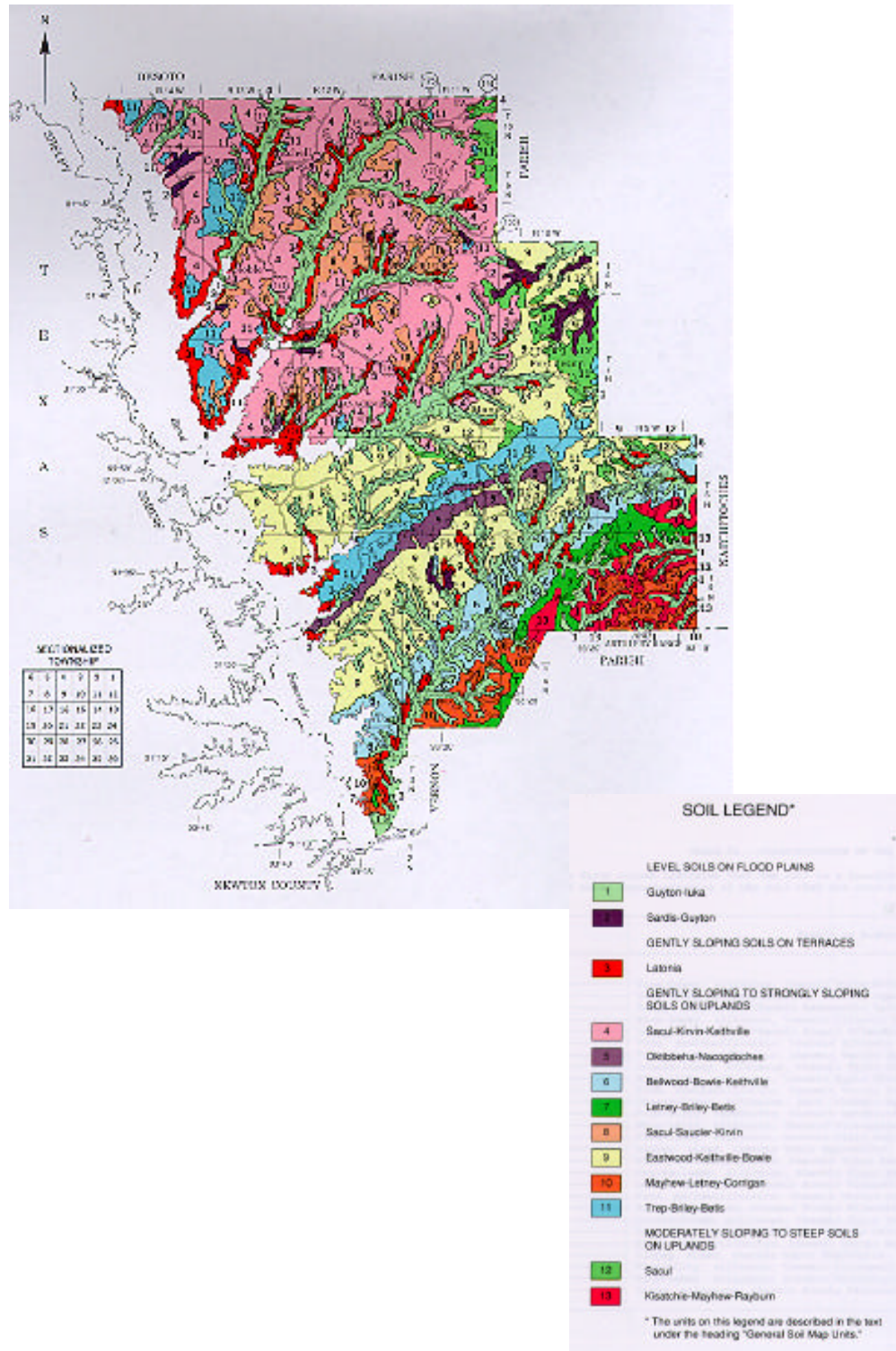
- ❖ basic geology ❖ general mineralogy ❖ surface slope (drainage)
- ❖ density ❖ internal drainage ❖ permeability
- ❖ water tables ❖ shrink-swell potential ❖ AASHTO and ASTM classifications
- ❖ organic content ❖ pH ❖ Atterbergs
- ❖ flooding history ❖ quality of material for roads
- ❖ corrosion characteristics ❖ quality for site development
- ❖ typical gradations ❖ erodibility

MANUFACTURED MATERIALS

Nature has not always placed construction's frequently used materials in appropriate abundance in all geographical areas. Therefore, a significant industry has developed to supplement the availability of naturally occurring materials. Commonly, rock mass and fragments are mined, crushed, washed, sorted and blended to meet specified requirements and ensure uniformity. These materials and naturally occurring soils are frequently treated, modified, conditioned and stabilized with a wide variety of manufactured products, primarily cement and lime, to improve their performance.

Additionally, various man-made materials are available for use in construction. These materials may be by-products of another industry (e.g., blast furnace slag) or be specifically manufactured as an engineering material (soil and shale fused at high temperatures).

The field of soil mechanics has expanded as additional manufactured materials have been made available to the construction industry. Testing regimens are generally similar to those of natural materials; however, their numerical test results and behavior may be significantly different. Also, the definitions of construction materials have expanded and become more inclusive as man made materials have proliferated. Project design, construction techniques, and materials design and testing are evolving to accommodate these materials, which also affect the economic considerations of the construction industry.



**General Soil Map
(Sabine Parish, LA)
Figure 12**



Figure 13
Soil Types Mapped on Aerial Photo

Economic Considerations

The construction of new roads and reconstruction of existing roads is a challenging and expensive endeavor. Road construction typically requires the use of significant quantities of aggregates in building the base and surface of a pavement, whether that be rigid or flexible. Aggregates are so prevalent in road construction, that this single use consumes over half the annual production of virgin aggregates in the U.S. This huge appetite for aggregate resources during the last 100 years of industrial development has severely depleted the supply of high-quality aggregate materials. Many areas which have traditionally had adequate supplies have experienced shortages. Metropolitan areas are especially vulnerable to scarce aggregate supplies because of depletion due to high demand in a small geographic area, and zoning restrictions near population centers. Additionally, environmental constraints make it more difficult and expensive to operate aggregate quarries. Rural areas are not immune either. Demand for increasingly scarce resources has raised costs substantially. The absence of concentrated demand in remote areas may require the purchase of aggregates from distant sources.

These factors make it incumbent upon those who design and construct pavements to carefully choose their construction materials. Whereas in years past, a designer might have selected a crushed aggregate base or subbase without much thought to alternative materials, the designer now needs to consider making most efficient use of locally available products, even if these are not high-quality soils or aggregates.

Consequently, the focus on using marginal or inferior materials has necessitated the development of methods to improve them so that they can be used in road construction. It is usually more economical to improve in-place materials than to remove and replace them with imported materials of higher quality. Cement and lime are commonly used as additives to improve less than ideal materials to make them usable for roadbuilding. Every road must be placed, at some point, on existing soils. Cement, lime, and other additives allow more soils to be used as the principal load-bearing element in the pavement structure.

SUMMARY

The goal of this section of the training material is to provide the student information on the origin of soils and to supply data on the types of soil which exist in specific areas of the continental United States, as well as the reasons that these soils are found in these locations. This information will enable the soil technician to predict the type of soil that is typical of a geographic area. The course has demonstrated by maps how vegetation, climate, topography and the location of dominant soil groups are closely related. It has also introduced information provided by the Natural Resources Conservation Service that can be used to further recognize soil type. This background knowledge will be of assistance to the soil technician in determining the validity of any testing regimen and subsequent numerical results and to make informed decisions regarding soil. Now the focus turns to testing and how to ensure the validity, accuracy and significance of the numerical results.

GLOSSARY

- aeolian** - in terms of soil generation, caused by wind erosion and transport
- alluvial** - in terms of soil generation, caused by water erosion and transport
- arid** - having little rainfall
- basalt** - igneous rock that has been ejected by volcanic activity to the surface of the earth's crust
- batholith** - large (greater than 40 square miles), intrusive, igneous mass of crystallized granitic rock, which usually form mountain cores
- biological weathering** - deterioration of parent material into soil caused by both chemical and physical forces, especially that of animal and plant activities
- borax** - a white crystalline mineral compound composed of a hydrated sodium borate ($\text{Na}_2\text{B}_4\text{O}_7$) that forms on the surface of stony soil in arid regions as a result of evaporation
- calcium carbonate** - a compound (CaCO_3) found in nature as calcite and aragonite and in combination in soil or rocks, such as limestone and caliche
- caliche** - a crust of calcium carbonate that forms on the stony soil of arid regions as a result of evaporation
- capillary action** - the attraction of water to a surface which causes it to rise against the force of gravity through surface tension.
- carbonation** - the dissolving of carbon dioxide in water to form carbonic acid, which reacts with calcium or other elements to form carbonates (e.g., limestone)
- chemical weathering** - deterioration of parent material into soil through chemical changes (e.g., carbonation, leaching, oxidation)
- clastic** - made up of fragments of preexisting rock
- colluvium** - rock detritus and soil accumulated at the foot of a slope
- continental divide** - the elevated divide that separates the directional flow of water to opposite sides effectively dividing the surface drainage of a continent.

continental drift	- the movement of continents around the earth through geologic time due to plate tectonics
core	- the central mass of high density material at the center of the earth
crust	- the outer layer of the earth's structure directly in contact with the atmosphere
crustal plates	- see tectonic plates
degradation	- disintegration
deposition	- the process carried out by wind, ice and water of moving material from one location to another
detritus	- loose material (e.g., rock fragments) that results directly from disintegration
diastrophism	- the process of deformation that produces the earth's crust, its continents and ocean basins, plateaus and mountains, strata folds, and faults
erosion	- wearing away
extrusion	- molten material (magma) from deep within the earth which has been ejected onto the surface through volcanic activity
fauna	- animal or animal life
flora	- plant life
geology	- the science that deals with the history of the earth, especially the study of rock forms
geotechnical	- having to do with the properties of soils
glacial	- having to do with the those parts of geologic time from Precambrian onward when a much larger portion of the earth was covered with sheets of ice
gleyed soils	- soil that formed under poor drainage; resulting in the reduction of iron and other elements in the profile and in gray and mottled colors, usually gray with yellow
granite	- a light colored predominately siliceous rock normally found in igneous intrusions
granular	- having a grainy texture

- gypsum**
- a widely distributed mineral (CaSO_4) consisting of calcium sulfate that forms on the stony soil of arid regions as a result of evaporation

heterogenous-	consisting of dissimilar components; nonuniform blend
horizon soil	- a layer of soil produced by soil forming processes, lying approximately parallel to the surface, having distinct characteristics
humid	- characterized by perceptible moisture; in climate terminology, exhibits rainfall between 40 - 80 inches per year
humus	- a brown or black complex variable material resulting from partial decomposition of plant or animal matter and forming the more stable organic portion of a soil
hydration	- a reaction of other chemical with those of water
igneous	- resulting from the intrusion or extrusion of magma or the activity of volcanoes; rocks formed from molten magma
intrusion	- molten crustal material that is injected into other rock through fissures and bedding planes
isostasy	- general equilibrium in the earth's crust maintained by a yielding flow of rock material in the mantle
leach	- to dissolve and remove soluble compounds from a substance by the action of water percolating through soils
magma	- molten rock
mantle	- the layer of the earth's structure lying immediately below the earth's crust
mass wasting-	the movement of rock debris downslope under the direct influence of gravity
metamorphic	- the type of rocks produced by a pronounced change of pressure, heat and water, resulting in a more compact and more highly crystalline condition
munsell color-	a designation of color by degrees of hue value and chroma
nomenclature-	a system of terms used in a particular discipline
organic	- plant and animal residue in the soil in various stages of decomposition
oxidation	- the process of chemically changing a compound through exposure to oxygen; reactions in which oxygen chemically reacts with a metal forming an oxide
parent rock	- the original rock formation; either the original rock mass or the clastic material in which soil forms

- permeability** - the quality of a soil that enables water to move through the profile
- physical weathering** - deterioration caused by agents such as wind, water, and ice
- plate tectonics** - the movement of the earth's crust divided into large pieces which float on a viscous material in the mantle
- reduction** - reaction, which occurs below the water table, which results in the freeing of a metal from its oxide; the opposite of oxidation
- relief** - the relative elevations of the land surface; topography
- saltation** - the bouncing of particles too large to be held in suspension
- sedimentary rock** - formed from materials transported by moving water, air or ice or chemically precipitated
- shear boundary** - the point of contact between two tectonic plates which move laterally to each other, resulting in and strike slip faults at their edges
- solum** - the altered layer of soil above the parent material that includes the A and B horizons
- solution** - the process by which a solid, liquid or gaseous substance is homogeneously mixed with a liquid
- spreading boundary** - occurs where two tectonic plates are moving away from each other
- subduction zone** - occurs where two tectonic plates are moving toward each other causing crustal material to be pushed beneath the plates
- suspension** - a substance in which the particles are mixed, but not dissolved in a liquid
- talus** - a slope formed by an accumulation of rock debris; rock debris at the base of a cliff
- topography** - the configuration of a surface including its relief and the position of its natural and man-made features
- traction** - the pushing, dragging or rolling of particles too large to be lifted by the transporting force
- true soil** - detritus which has been weathered to the point that it has an identifiable

layering into specific horizons

- tundra** - a level or undulating treeless plain, characteristic of arctic and subarctic regions; consists of black mucky soil with a permanently frozen subsoil
- vulcanism** - (also volcanism); the power or action of a volcano
- weathering** - the action of the elements in altering the texture, composition or form of exposed objects; the physical disintegration and chemical decomposition of earth materials

DESCRIPTION AND IDENTIFICATION
OF SOILS
(VISUAL-MANUAL PROCEDURE)
UNIFIED METHOD
ASTM D 2488



Developed by
FHWA Multi-regional Soils Training & Certification Group

NOTE

Successful completion of the following training materials, including examination and performance evaluation is prerequisites for this training package.

- ▶ AASHTO T 265, Laboratory Determination of Moisture Content of Soils
- ▶ AASHTO T 88, Particle Size Analysis of Soil
- ▶ AASHTO T 89, Determining the Liquid Limit of Soil
- ▶ AASHTO T90, Determining the Plastic Limit and Plasticity Index of Soil

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DESCRIPTION AND IDENTIFICATION OF SOIL BY THE UNIFIED METHOD (VISUAL-MANUAL METHOD)

Soil exists throughout the world in a wide variety of types. Different types of soil exhibit diverse behavior properties. The engineering properties of soils are governed by their physical properties. Therefore, we need to describe and identify soils in terms that will convey this information clearly and accurately.

This procedure describes a prudent visual, tactile, and somewhat olfactory inspection along with a few simple tests that can be performed to provide an initial appraisal of the naturally occurring soil in a given area. This information can be helpful in the initial planning and in relating field observations to laboratory test results. This means that this type of soil appraisal should clearly describe the soil using appropriate and recognizable terminology.

Summary of Testing

Until now, we have been concerned with identifying soils by giving them basic descriptive names and group symbols. There is additional information that should be included in any soil description. This information includes angularity and shape of the coarse particles in the soil, soil color, odor, moisture condition, extent of reaction with hydrochloric acid, soil consistency, cementation, structure of intact soil, range of particle sizes, maximum particle size present, hardness of coarse sand and larger particles, presence of roots, mica, gypsum or extraneous materials (like glass, brick, lumber, etc.), local or commercial name and/or geologic interpretation of the soil.

Typical Test Results

The test results from this procedure would appear in the following format:

- ▶ **Well-Graded Gravel with Sand (GW)** - About 75% fine to coarse, hard, subangular gravel; about 25% fine to coarse, hard, subangular sand; trace of fines; maximum size, 75 mm, brown, dry; no reaction with HCl.
- ▶ **Silty Sand with Organic Fines (SM)** - About 75% fine to coarse, hard, subangular reddish sand; about 25% organic and silty dark brown non-plastic fines with no dry strength and slow dilatancy; wet; maximum size, coarse sand; weak reaction to HCl.

Common Testing Errors

- ▶ Failure to protect samples from changes in moisture content will affect the results of this test.
- ▶ Not careful in reading the charts and tables used in this method, it is very easy to misinterpret the data. Read and record, then read again.
- ▶ Failures to correctly estimate the percentage of sand, gravel and fines in a sample. This is something that is best learned by comparing one's own visual estimate with a laboratory particle size analysis. Of course the laboratory analysis will be more accurate, but the technician should strive to estimate within 5% of the laboratory values.
- ▶ Failure to examine the entire sample. For instance, when examining a sack of soil obtained from a backhoe excavation, be sure to remove the material from the sack. Do not get lazy and just classify the material at the open end of the sack. The particle sizes at the top and bottom of the sack are likely to be different. Always strive to examine the total sample, not just part.
- ▶ Failure to, when performing the dry strength, dilatancy and toughness tests on fine-grained soils, remove particles larger than the 425 μm sieve. The larger particles may affect the results.
- ▶ Failure to breakdown aggregations of soil into their individual constituents before making particle size determinations. Practically, this means do not identify a 25-mm clay clod as a piece of gravel.

Test Methodology

Apparatus

Before beginning any procedure, you must first assemble all the equipment you will need to conduct the procedure. For this procedure you will need the following.

- ▶ Pocket knife or small spatula
- ▶ Small test tube with stopper or jar with lid
- ▶ Small hand lens
- ▶ Water (either tap water or natural source)
- ▶ Hydrochloric acid, diluted in a small bottle, one part HCl (10N) to three parts distilled water.
- ▶ Sieves: 75 mm
4.75 mm
425 μ m

NOTE

There is a safety hazard in preparing any acid solution: When preparing the dilute HCl solution, slowly add acid to the water, being careful not to spill any acid or splash acid onto any person or surface. Handle this acid and the dilute solution with caution and store safely. **If the solution comes in contact with the skin, rinse the affected area thoroughly with water. Do not add water to acid.**

SAMPLE

- ▶ Select a representative sample of soil to be identified. The sample shall be considered to be representative of a stratum, if it was obtained by an appropriate, accepted or standard procedure, such as:

ASTM Practices

- D 1452 - Soil Investigation and Sampling by Auger Boring
 - D 1587 - Thin-walled Tube Sampling of Soils
 - D 2113 - Diamond Core Drilling for Site Investigation
 - D 1586 - Penetration Test and Split-Barrel Sampling of Soils
- ▶ Make sure the sample is carefully identified as to its origin. This may take the form of a boring number and sample number in conjunction with a job number, a stratum, a horizon or a location description with respect to a permanent monument, a grid system, or a station number and offset with respect to a stated centerline and a depth or elevation.

- ▶ Selecting an appropriate specimen size for examination is very important for an accurate description and identification. The minimum amount of material selected for examination should be in accordance with the following schedule:

Maximum Particle Size, Sieve opening	Minimum Specimen Size, Dry Mass
4.75 mm	100 g
9.5 mm	200 g
19.0 mm	1.0 kg
38.1 mm	8.0 kg
75.0 mm	60.0 kg

If a sample contains random isolated particles that are significantly larger than the particles in the soil matrix, the soil matrix can accurately identified in accordance with the preceding schedule.

- If the field sample or specimen being examined is smaller than the minimum recommended amount, the report shall include an appropriate remark to that effect.

PROCEDURE

Description Information for Soils

- ▶ **Angularity** - Describe the angularity of the coarse sand, gravel, cobbles, and boulders as angular, sub-angular, sub-rounded, or rounded. A range of angularity may be stated, such as sub-rounded to round. Each material should be accessed in accordance with the following:
 - **Angular** - particles have sharp edges and relatively plane sides with unpolished surfaces.
 - **Sub-angular** - particles are similar to angular description but have rounded edges
 - **Sub-rounded** - particles have nearly plane sides but have well rounded edges and corners
 - **Rounded** - particles have smoothly curved sides and no corners.
- ▶ **Shape** - Describe the shape of gravel, cobbles, and boulders as flat, elongated, or flat and elongated, as described later in this section, if they meet the criteria. Otherwise, do not mention the shape. Indicate the fraction of the particles that have that shape, such as: One-third of the gravel particles are flat.
 - **Flat** - particles with a ratio of width/thickness >3
 - **Elongated** - particles with a ratio of length/width >3
 - **Flat and elongated** - particles meet the criteria for both flat and elongated.

- ▶ **Color** - Describe the color. Color is an important property in identifying organic soils, and within a given locality it may also be useful in identifying materials of similar geologic origin. If the sample has patches or layers of varying colors, this shall be noted and all representative colors described. The color shall be described from moist samples. If color represents a dry condition, this shall be stated in the report. For standard colors reference Soils, Their Origin and Their Existence (Munsell System of Color Notation)
- ▶ **Odor** - Describe the odor if organic or unusual. Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation. This is especially apparent in fresh samples, but if samples are dried, heating a moistened sample may often revive the odor. If the odor is unusual (petroleum product, chemical, and the like) it must be described.
- ▶ **Moisture Condition** - Describe the moisture condition as dry, moist, or wet in accordance with the following:
 - **Dry** - Absence of moisture, dusty, dry to the touch
 - **Moist** - Damp, but no visible water
 - **Wet** - Visible free water, usually soil is below water table
- ▶ **HCl Reaction** - Place a few drops of HCl solution on the soil, describe the reaction between the acid solution and the soil as none, weak, or strong in accordance with criteria given in this section. Since calcium carbonate is a common cementing agent, reporting of its presence on the basis of the reaction with the acid solution is important. Depending on the local conditions and the geologic history of a region, this reaction could also indicate the presence of undesirable materials such as Marl.
 - **None** - No visible reaction
 - **Weak** - Some reaction with bubbles forming slowly
 - **Strong** - Violent reaction with bubbles forming immediately
- ▶ **Consistency** - for intact fine-grained soils that are at or very near their natural moisture content, and which do not contain significant amounts of gravel, press the thumb slowly into the sample, and describe the consistency as very soft, soft, firm, hard, or very hard in accordance with the following:
 - **Very soft** - thumb will penetrate soil more than 25 mm (1 in.)
 - **Soft** - thumb will penetrate about 25 mm (1 in.)
 - **Firm** - thumb will indent soil about 6 mm (1/4 in.)
 - **Hard** - thumb will not indent soil, but readily indents with thumbnail
 - **Very hard** - thumbnail will not indent soil
- ▶ **Cementation** - describe the cementation of intact coarse-grained soils by pressing the soil between the thumb and forefinger and classify it in accordance with the following:
 - **Weak** - Crumbles or breaks with handling or very little finger pressure
 - **Moderate** - Crumbles or breaks with considerable finger pressure
 - **Strong** - Will not crumble or break with finger pressure

- ▶ **Structure** - describe the structure of the intact soil by observing the soil in day light or good artificial light using the following :
 - **Stratified** - alternating layers of varying material or color with layers at least 6 mm thick
 - **Laminated** - alternating layer of varying materials or color with layers less than 6 mm thick
 - **Fissured** - breaks along definite planes of fracture with little resistance to fracturing
 - **Slickensided** - fractured planes or bedding planes, having moved, appear polished or glossy
 - **Blocky** - cohesive soil that can be broken down into small angular lumps, which resist further breakdown
 - **Lense** - small lense shaped pockets of different soils, such as small lenses of sand scattered through a mass of clay
 - **Homogeneous** - same color and appearance throughout
- **Range of particle sizes** - for gravel and sand components, describe the range of particle sizes within each component as explained in the “Definitions” section. For example, about 20% fine to coarse to gravel, about 40% fine to coarse sand. (See Figure 1)
- ▶ **Maximum particle size** - describe the maximum particle size in accordance with the following:
 - **Sand size** - if the maximum particle size is a sand size, describe as fine, medium, or coarse in accordance with the “Definitions” section. For example, maximum particle size, medium sand
 - **Gravel size** - If the maximum particle is a gravel size, describe the maximum particle size as the smallest sieve opening that the particle will pass. For example, maximum particle size is 38 mm (will pass a 38 mm square opening, but not a 19 mm square opening)
 - **Cobble or Boulder size** - if the maximum particle size is cobble or boulder size, describe the maximum dimension of the largest particle. For example, maximum dimension, 450 mm.
- ▶ **Hardness** - describe the hardness of coarse sand and larger particles by striking the particle with a hammer on a solid surface and describing what occurs. For example: gravel-size particles fracture with considerable hammer blow, some gravel size particles crumble with hammer blow. “Hard” means the particles do not crack, fracture or crumble under a hammer blow.

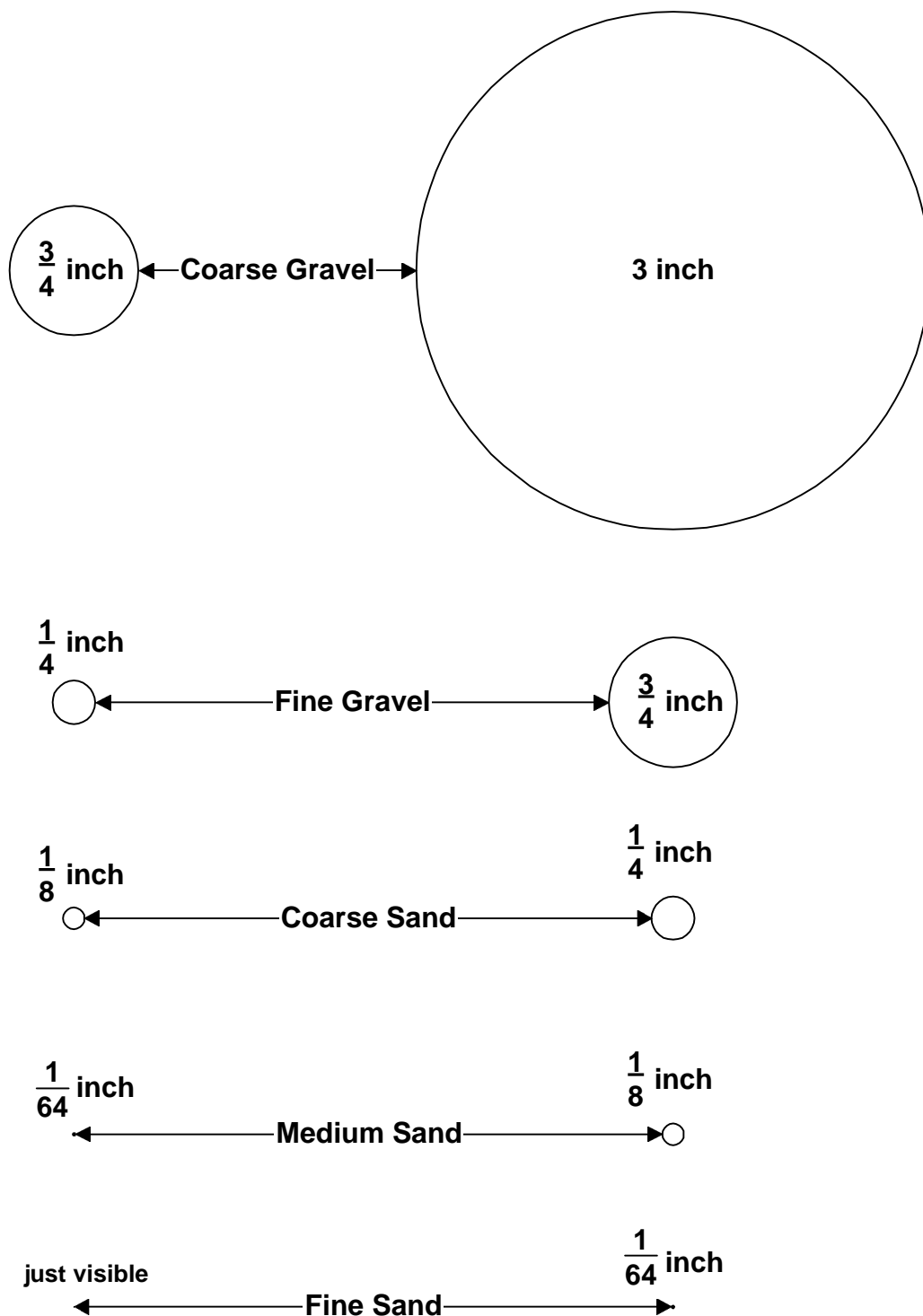


Figure 1 - Illustration of Particle Size

Additional comments shall be added; such as the presence of roots or root holes, difficulty in drilling or auguring the hole, caving of trench or hole, or the presence of mica.

- ▶ The use of commercial or local name, or a geological interpretation of the soil, may be added if appropriate.
- ▶ Classification or identification of the soil by other classification systems may be added if identified as such.

Identification of Peat

A sample composed primarily of vegetable tissue in various stage of decomposition, that has a fibrous to amorphous texture, usually a dark brown to black color, and an organic odor, shall be designated as a highly organic soil and shall be identified as peat, PT, and not be subjected to the identification procedures described hereafter.

Preparation for Identification

- ▶ The soil identification portion of this practice is based on the portion of the soil that will pass a 75 mm sieve. The larger particles must be removed manually in loose sample, or mentally for an intact sample before classifying the soil.
- ▶ Estimate and note the percentages of cobbles and boulders.
- ▶ For the fraction that passes the 75 mm sieve, estimate the percentages of gravel, sand, and fines based on dry weight. This may be done by one of the following methods:
 - **Jar Method** - The relative percentage of coarse and fine-grained material may be estimated thoroughly shaking a mixture of soil and water in a jar and then allowing the mixture to settle. The coarse particles will fall to the bottom and successively finer particles will be deposited with increasing time; the sand sizes will fall out of suspension in 20 to 30 seconds. The relative proportions can be estimated from the volume of each size.
 - **Visual Method** - Mentally visualize the gravel size particles placed in sacks or other containers. Then do the same with the sand size particles and the fines. Mentally compare the number of plus 4.75 sieve size and minus 4.75 sieve size present. The percentages of sand and fines in the minus 4.75 sieve material can be estimated from the wash test.
 - **Wash Test** - Select and moisten enough minus 4.75 sieve size material to form a 25 mm cube of soil. Cut the cube in half, set one half aside, and place the other half in a small dish. Wash and decant the fines out of the material in the dish until the wash water is clear and then compare the two samples and estimate the percentage of sand and fines. Remember that the percentage is based on weight not volume. However, the volume percentages will provide a reasonable indication of grain size percentages.

- ▶ The percentages shall be estimated to the nearest 5 %. the percentages of gravel, sand and fines shall total 100%.
- ▶ If one of the components is present, but not on sufficient quantity to be considered 5% of the smaller than 75 mm portion indicate its presence by the word “trace”. A trace is not considered in the total 100% of the components.

Preliminary Identification

- ▶ The soil is fine-grained if it contains 50% or more fines. Follow the procedure for identifying fine-grained soils. (see figure 2)
- ▶ The soil is coarse-grained if it contains less than 50 % fines. Follow the procedures for identifying coarse-grained soils. (see figure 3)

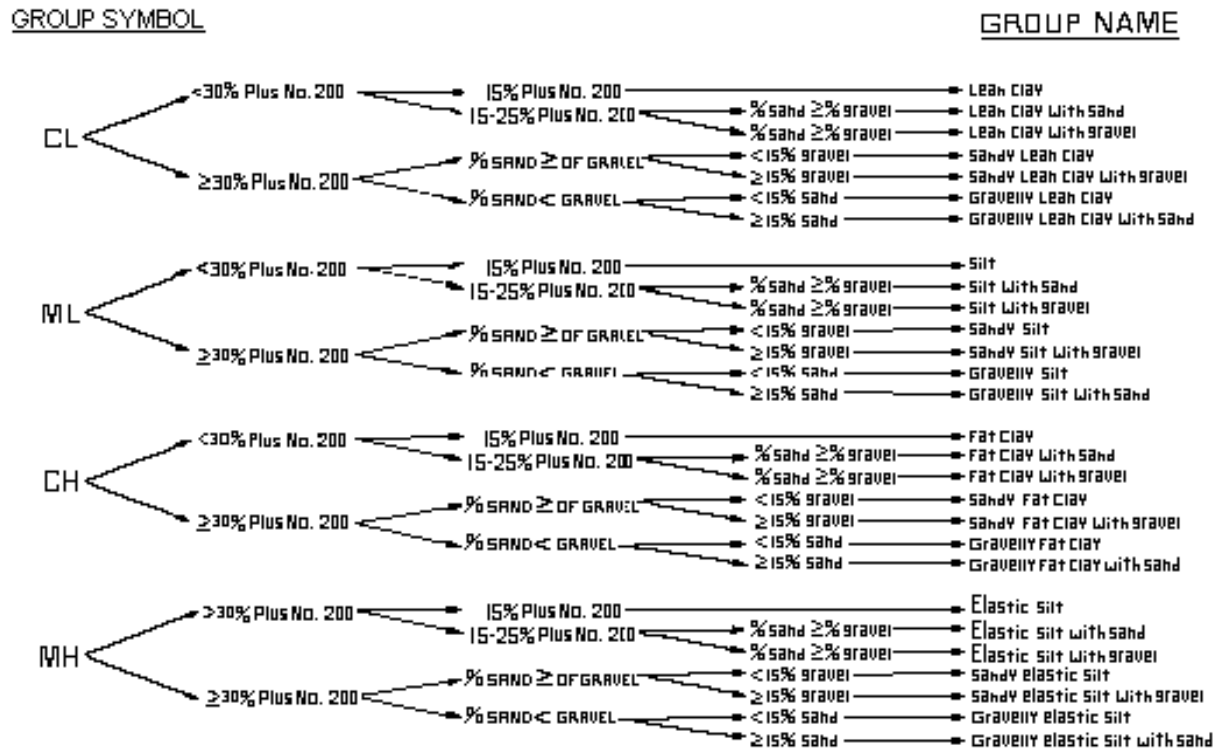


Figure 2 - Flow Chart for fine-Grained Inorganic Soils

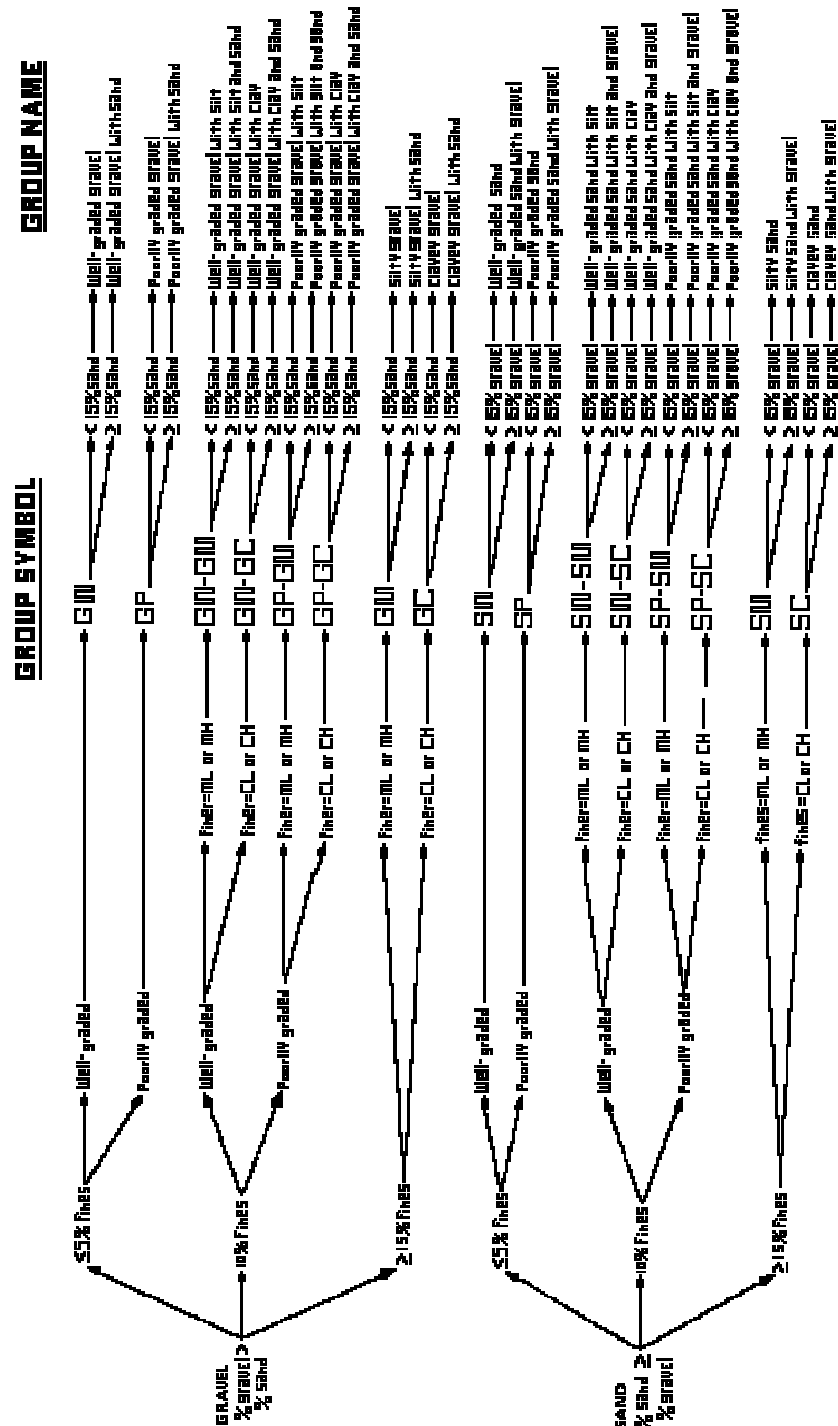


Figure 3 - Flow Chart for Coarse-Grained Inorganic Soils

Procedur
identifyin
grained

e for
g fine-
Soils

- ▶ Select a representative sample of the material for examination. Remove particles larger than 425 mm sieve, until a specimen equivalent to about a handful of material is available. Use this specimen for performing the dry strength, dilatancy, and toughness tests.

- ▶ **Dry Strength**

- From the specimen, select enough material to mold into a ball about 50 mm in diameter. Mold the material until it has the consistency of putty, adding water if necessary.
- From the molded material, take at least three specimens. A test specimen shall be a ball of material about 13 mm in diameter. Allow the specimens to dry in air, sun, or by artificial means, as long as the temperature does not exceed 60° C.
- Test the strength of the dry balls by crushing between the fingers. Based on the following criteria describe the dry strength as:

None - the dry specimen crumbles into powder with mere pressure of handling.

Low - the specimen crumbles to powder with some finger pressure.

Medium - the dry specimen breaks into pieces or crumbles with considerable finger pressure.

High - the dry specimen cannot be broken with finger pressure. Specimen will break into

pieces between thumb and a hard surface

Very High - Dry specimen cannot be broken between thumb and hard surface.

NOTE

The presence of high strength , may indicate the presence of water soluble cementing materials, such as calcium carbonate. Calcium carbonate can usually be detected by the intensity of the reaction with dilute hydrochloric acid.

- ▶ **Dilatancy**

- From the specimen, select enough material to mold another ball about 13 mm in diameter. Mold the material, adding water if necessary, until it has a soft but not sticky consistency.

Smooth the ball in the palm of one hand with the blade of a knife or small spatula. Shake the hand horizontally, striking the side of the hand vigorously against the other hand several times. Note the reaction of water appearing on the surface of the soil. Squeeze the sample by closing the hand or pinching the soil between the finger. Note the description in accordance with the following criteria:

None - No visible change in the specimen.

Slow - Water appears slowly on the surface of the specimen during the shaking and

does not disappear or disappears slowly upon squeezing.

Rapid - Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing.

► **Toughness**

- Following the completion of the dilatancy test, the test specimen is shaped into an elongated pat and rolled by hand on a smooth surface or between the palms into a thread 3 mm in diameter. (If the thread is too wet to roll easily, it should be spread into a thin layer and allowed to lose some water by evaporation.) Fold the sample threads and re-roll repeatedly until the thread crumbles at a diameter of about 3 mm. The thread will crumble at about 3 mm when the soil is near the plastic limit. Note the pressure required to roll the thread near the plastic limit. Also, note the strength of the thread. After the thread crumbles, the pieces should be lumped together and kneaded until the lump crumbles. Note the toughness of the material during kneading.

- Describe the toughness of the thread and lump in accordance with the following:

Low - only slight pressure is required to roll the thread near the plastic limit. The thread and lump are soft and weak.

Medium - moderate pressure is required to roll the thread near the plastic limit. The thread and lump have moderate stiffness.

High - Considerable pressure is required to roll the thread to near the plastic limit. The thread and lump are very stiff.

► **Plasticity**

- On the basis of observations made during the toughness test, describe the plasticity of the material in accordance with the following:

Non-plastic - a 3 mm thread cannot be rolled at any moisture content.

Low - the thread can barely be rolled and the lump can not be formed when drier than the plastic limit.

Medium - the thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be re-rolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.

High - it takes considerable time rolling and kneading to reach the plastic limit. The thread can be re-rolled several times after being rolled to 3 mm the first time. The lump can be formed without crumbling when drier than the plastic limit.

Decide whether the soil is an *inorganic* or an *organic* fine-grained soil and follow the appropriate section given next.

Identification of Inorganic fine-grained Soils

- ▶ The basis of the dry strength, dilatancy, plasticity and toughness tests, identify the soil as one of the following:

Soil Symbol/Name	Dry Strength	Dilatancy	Toughness
ML/Inorganic Silt	None to Low	Slow to Rapid	Low or thread cannot be formed
CL/Inorganic Lean Clay	Medium to High	None to Slow	Medium
MH/Inorganic elastic	Low to Medium	None to Slow	Low to Medium
CH/Inorganic Fat Clay	High to Very High	None	High

- ▶ If the soil is estimated to have 15% to 25% sand or gravel, or both, the words “with sand” or “with gravel” (which ever is more predominant) shall be added to the group name. For example: *lean clay with sand*, (CL), or *silt with gravel*, (ML). If the percentage of sand is equal to the percentage of gravel, use “with sand”. (see Figure 2)
- ▶ If the soil is estimated to have 30% or more sand or gravel, or both, the words “sandy” or “gravelly” shall be added to the group name. Add the appropriate word depending on which is predominant in the sample. For example: *sandy lean clay*, (CL); *gravelly fat clay*, (CH), or *sandy silt*, (ML). If the percentage of sand is equal to the percentage of gravel, then use “sandy”. (see Figure 2)

Identification of Organic fine-grained Soils

- ▶ Identify the soil as an *organic soil*, (OL/OH), if the soil contains enough organic particles to influence soil properties. Organic soils usually have a dark brown to black color and may have an organic odor. Often, organic soils will change color, for example, black to brown, when exposed to air. Some organic soils will lighten in color significantly when air dried. Organic soils will not have a high toughness or plasticity. The thread for the toughness will be spongy. (see Figure 2)

Procedures for Identifying Coarse-Grained Soils (Contains less than 50% fines)

- ▶ The soil is a *gravel* if the percentage of gravel is estimated to be more than the percentage of sand.
- ▶ The soil is a *sand* if the percentage of gravel is estimated to be equal to or less than the percentage sand.

- ▶ The soil is a *clean gravel* or *clean sand* if the percentage of fines is estimated to be 5% or less.
 - Identify the soil as a *well-graded gravel*, (GW), or as a *well-graded sand*, (SW), if it has a wide range of particle sizes and substantial amounts of the intermediate particle sizes. (see Figure 3)
 - Identify the soil as a *poorly graded gravel*, (GP), or as a *poorly graded sand*, (SP), if it consists predominately of one size (uniformly graded) or it has a wide range of sizes with some intermediate sizes obviously missing.
 - The soil is classified as either *gravel with fines* or a *sand with fines* if the percentage of fines is estimated to be 15% or more.
 - Identify the soil as a *clayey gravel*, (GC), or a *clayey sand*, (SC), if the fines are clayey as previously determined.
 - Identify the soil as a *silty gravel*, (GM), or a *silty sand*, (SM), if the fines are silty as previously determined.
- ▶ If the soil is estimated to contain 10% fines, give the soil a dual identification using two group symbols.
 - The first group symbol shall correspond to clean gravel or sand (GW, GP, SW, SP), and the second symbol shall correspond to a gravel or sand with fines (GC, GM, SC, and SM)
 - The group name shall correspond to the first group symbol plus the words “with clay” or “with silt” to indicate the plasticity characteristics of the fines. For example: *well-graded gravel with clay*, (GW-GC) or *poorly-graded sand with silt*, (SP-SM).
- ▶ If the specimen is predominately sand or gravel, but contains an estimated 15% or more of the other coarse-grained, the words “with gravel” or “with sand” shall be added to the group name. For example: *poorly graded gravel with sand*, (GP) or *clayey sand with gravel*, (SC).
- ▶ If the field sample contains any cobbles or boulders, or both, the words “with cobbles” or “with cobbles and boulders” shall be added to the group name.

Report

1. Group Name
2. Group Symbol
3. Percent cobbles or boulders, or both (by volume)
4. Percent of gravel, sand, or fines, or all three (by dry weight)
5. Particle size range:
 - Gravel-fine, coarse
 - Sand-fine, medium, coarse
6. Particle angularity:

- angular
 - subangular
 - subrounded
 - rounded
7. Particle shape: (if appropriate)
- flat
 - elongated
 - flat and elongated
8. Maximum particle size or dimension
9. Hardness of coarse sand and larger particles
10. Plasticity of fines:
- nonplastic
 - low
 - medium
 - high
11. Dry strength:
- none
 - low
 - medium
 - high very high
12. Dilatancy:
- none
 - slow
 - rapid
13. Toughness:
- low
 - medium
 - high
14. Color (in moist condition)
15. Odor (mention only if organic or unusual)
16. Moisture:
- dry
 - moist
 - wet
17. Reaction with HCl:
- none
 - weak
 - strong

For intact samples:

1. Consistency: (fine-grained soils only)
- very soft
 - soft
 - firm
 - hard

- very hard
- 2. Structure:
 - stratified
 - laminated
 - fissured
 - Slickensided
 - Lensed
 - homogeneous
- 3. Cementation:
 - weak
 - moderate
 - strong
- 4. Local name
- 5. Geologic interpretation
- 6. Additional Comments: (such as)
 - presence of roots
 - presence of mica, gypsum, etc.
 - surface coatings on coarse particles
 - caving or sloughing of auger hole or trench sides.
- 7. Difficulty in auguring or excavating, etc.

Glossary

For particles retained on a 75 mm sieve, the following definitions are suggested:

- Boulders** - Particles of rock that will not pass a 75 mm square opening.
- Cobbles** - particles of rock that will pass a 300 mm square opening and be retained on a 75 mm sieve.
 Gravel - particles of rock that will pass a 75 mm sieve and be retained on a 4.75 mm sieve with the following sub-divisions:
 coarse - passes a 75 mm sieve and is retained on a 19 mm sieve.
 fine - Passes a 19 mm sieve and is retained on a 4.75 mm sieve
- Sand** - Particles of rock that will pass a 4.75 mm sieve and be retained on a 0.075 mm sieve with the following sub-divisions:
 coarse - passes a 4.75 mm sieve and is retained on a 2.00 mm sieve
 medium - passes a 2.00 mm sieve and is retained on a 0.425 mm
 fine - passes a 0.425 mm sieve and is retained on a 0.075 mm
- Fines** - That material which is non-organic, and passes a 0.075 mm sieve.
- Silt** - Soil passing a 0.075 mm sieve that is non-plastic or very slightly plastic and that exhibits little or no strength when air dry. For classification, a silt is a fine-grained soil, or the fine-grained portion of soil, with a plasticity index less than 4, and the plot of plasticity index versus liquid limit falls below the "A" line. (see figure 4)
- Clay** - Soil passing the 0.075 mm sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents and that exhibits considerable strength when dry. For classification, a clay is a fine-grained soil, or the fine-grained portion of soil, with a plasticity index greater than 4, and the plot of plasticity index versus liquid limit falls on or above the "A" line. (see figure 4)
- Organic silt** - A silt with sufficient organic content to influence the soil properties. For classification, an organic silt is a soil would be classified as a silt except that its liquid limit value after oven drying is less than 75% of its liquid limit value before oven drying.
- Organic clay** - A clay with sufficient organic content to influence the soil properties. For classification, an organic clay is a soil would be classified as a clay except that its liquid limit value after oven drying is less than 75% of its liquid limit value before oven drying.
- Peat** - A soil comprised primarily of vegetable tissue in various stages of decomposition, usually with an organic odor, a dark brown to black color, a

spongy consistency, and a texture ranging from fibrous to amorphous (completely decomposed).

Olfactory - Sense of smell.

Tactile - Sense of touch.

Mica - A mineral composed of very thin friable plates.

Soil - Mineral particles which have been naturally degraded from mass rock.

The visual-manual procedure covered in this manual utilizes the following group symbols:

G gravel
S sand
M silt
C clay
O organic
PT peat
W well graded
P poorly graded

RANDOM SAMPLING OF CONSTRUCTION MATERIALS

ASTM D 3665



Developed by
FHWA Multi-Regional Soils Training & Certification Group

NOTE

There are no prerequisites for this module.

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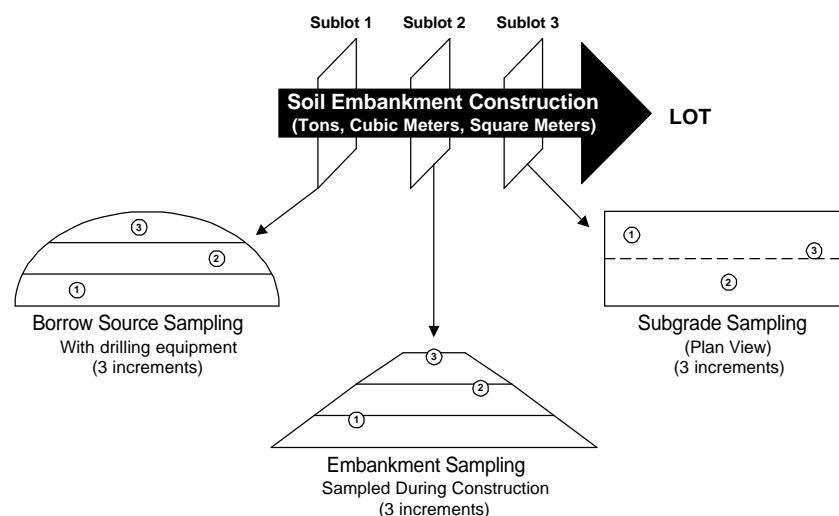
RANDOM SAMPLING OF CONSTRUCTION MATERIALS

This procedure provides a method to select random locations or times at which samples of construction materials are to be taken.

Highway construction materials are typically accepted or rejected based on the test results of small representative samples. Consequently, acceptance or rejection of materials is highly dependent on how well a small sample represents a larger quantity of material. If the sample is not truly representative of the larger quantity, acceptable material could be rejected, or substandard material accepted. Correct sampling methods are critical to the validity of the sample test results. Sampling performed incorrectly will lead to test results that do not reflect the true characteristics of the material or product being tested.

The actions required to obtain a good sample, such as how to take the sample, where to take it, what tools to use and the size of sample are covered in the appropriate materials control program and guidelines specified by the agency for use on the project. Reference should be made to these instructions on sampling requirements.

When a sample is not representative or random, it is said to be biased. Examples of biased sampling that should not be used include sampling an embankment at a given interval, such as every 500 meters; sampling borrow material at a given frequency, such as every fifth truckload, or taking samples at a given time frequency, such as every hour on the hour. Random sampling is used to eliminate bias in selecting a location or time for sampling. A random sample is any sample which has an equal chance as any other sample of being selected from a large quantity. In other words, there is an equal chance for all locations and all fractions of a large quantity of material to be sampled.



Sampling Situations for Soils

Figure 1.

Random Sampling

Example of

Soil-D3665-1

Random unbiased samples must represent the true nature of the material. Samples should not be obtained on a predetermined basis or based on the quality of the material in a certain area. If sampling is not performed on a random basis, the quality of the sample can be artificially modified causing sample to no longer be representative of the larger quantity. Specifications will identify lot size, location and frequencies for sampling and testing.

A lot is defined as a given quantity of material that is to be sampled. The lot is a predetermined unit which may represent a day's production, a specified quantity of material, a specified number of truckloads, or an interval of time. Agencies will usually specify the lot size and sampling frequency. Although these frequencies may appear to be a violation of random sampling, they are given as a minimum amount of sampling, not as a specific frequency. Lots are often divided into sublots. The number of sublots used to represent the lot will be determined by the agency and specifications. It may be necessary to take multiple samples and combine them to represent a unit. For example, three samples may be taken from borrow source and combined to form the sample unit. Several sample units will then be tested to determine the compliance of a subplot or lot to specifications. The use of random samples from sublots is referred to as stratified random sampling. Stratified random sampling assures that samples are taken from throughout the entire lot and are not concentrated in one area of the lot. See Figure 2.

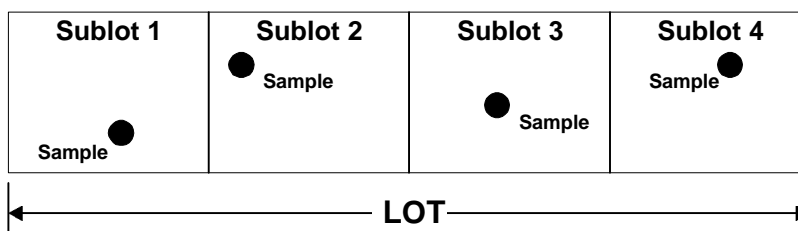


Figure 2.

stratified sampling

Quality control/quality assurance specifications are developed based on statistical theory which is valid only when random sampling is performed. QC/QA specifications are statistically based on a normal distribution (bell curve) of uniform material production. If samples are biased or not random, the test results will not fit the normal distribution and the QC/QA specification will no longer be valid. However, although it is not random, it is highly recommended that correlation sampling and testing be performed between the QC and QA labs before or at the beginning of production to identify any discrepancies between the sampling and testing procedures of the two labs and technicians.

Random sampling is usually accomplished with the use of random number generators or tables of random numbers. Most calculators and computers contain a random number generator that merely requires the operator to hit a button. The automated random number generators use programmed tables of random numbers similar to the tables included later. Random number tables are simply random arrangements of numbers of any table length.

Do not attempt to create your own method of being random! There is no way you will be able to avoid personal bias or the creation of bias.

SUMMARY OF TESTING

ASTM D 3665 - "Standard Practice for Random Sampling of Construction Materials," is a method used by the industry for determining random locations or time intervals at which samples of construction materials are to be taken. The ASTM method uses tables of random numbers and describes the procedures for determining random times for:

- ! belt sampling
- ! random locations for windrow and stockpile sampling
- ! random sampling of in-place paving materials
- ! random sampling of truck loads

This method does not describe actual sampling procedure, but rather, how to determine sampling times or locations.

TEST METHODOLOGY

Picking Random Numbers

The random number tables adapted from ASTM D 3665 and presented on the following pages contain all the numbers from 0.001 to 1.000. Each number appears only once. Obtain two "pill boxes," one box containing 100 "pills" numbered from 1 to 100 used for row determination in the table, and the other box containing 10 "pills" numbered from 0 to 9 used for column determination in the table.

1. Select a pill from the box containing 100 pills. For this exercise, say you've selected the pill with number .031. The first two digits give the table row number for the final random number that will be selected. For the selected pill number of .031, we'll use row 03 of the table. Always return the selected pill back into the box for further selections.
2. Select a pill from the box containing 10 pills. Say the selected pill results in a random number of .051. Use the first digit to designate the column number. In this case, the column number is 0. Again, return the selected pill back into the box for further selections.
3. Now locate the final random number in the table located at the intersection of row 03 and column 0. That number is .039, which is the random number which should be used for the determination of a sampling location.

Keep in mind that for most situations, you're going to need to pick several random numbers in order to obtain a final random number. This can take some time using the recommended procedure. Alternately, a calculator or computer with a random number generation function may be used.

EXAMPLES OF RANDOM SAMPLING PROCEDURES USING RANDOM NUMBERS

Sampling from a Borrow Source: Determine an amount of material to be considered a lot. Agencies may specify the number of samples based on the amount of borrow needed or sample depths based on types of soil present. A minimum number of samples for each borrow site may also be specified.

Example:

The lot size is 1500 cubic meters. For this example, the lot represents a volume 25 meters long by 20 meters wide by 3 meters deep. Specifications require that at least three locations shall be sampled. Two sets of three random numbers are needed to determine where holes will be dug or drilled to obtain samples. Also, based on your agency's practice or specification, either a composite sample will be obtained to represent the entire 3 meter depth or a third set of random numbers will be needed to determine the depth from which the sample will be obtained. Random numbers chosen from a table are as follows:

Random numbers:

Set 1: .20 .82 .70

Set 2: .04 .49 .98

Sample locations within the borrow area are determined as follows:

Sample #1:

$X = .20 \times 25$ (length of borrow) = 5.0 meters

$Y = .04 \times 20$ (width of borrow) = 0.8 meters

Sample #2:

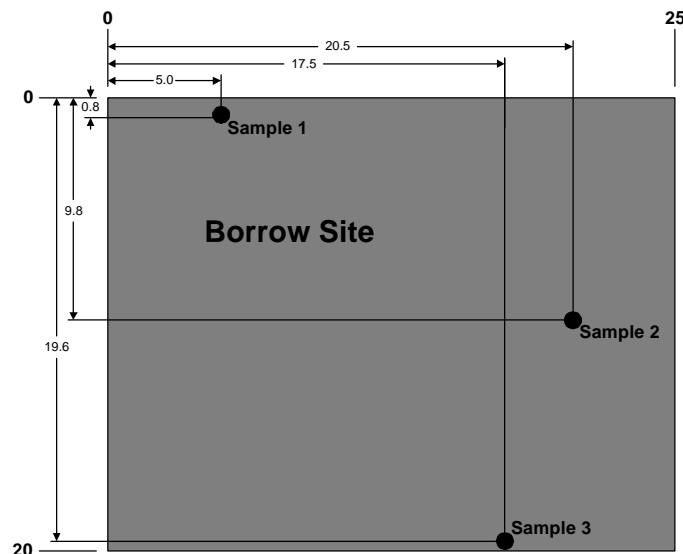
$X = .82 \times 25 = 20.5$

$Y = .49 \times 20 = 9.8$

Sample #3:

$X = .70 \times 25 = 17.5$

$Y = .98 \times 20 = 19.6$



Sampling
Determine
comprise a

from Haul Units:
the number of units that
lot. Multiply selected

random numbers by the number of haul units to determine sampling locations. In most cases, the number of haul units of material will be anticipated at the beginning of the lot's production. Some agencies determine lot size based on tonnage shipped to projects, in which case the random numbers are multiplied by the total anticipated tonnage to determine sampling locations.

Example:

Approximately 850 tons of a material will be delivered to the job site in 54 loads. If specifications require at least one sample be taken to represent each 250 tons of material, the number of samples necessary can be calculated by dividing the total sample by the amount each sample represents. Therefore:

$$850 \text{ tons} / 250 \text{ tons} = 3.4 \text{ samples required}$$

This number is rounded up to the next whole number. In this case, 4 samples will be required to represent the 54 loads of material. Four random numbers are then chosen to determine which loads will be sampled. In this case, a computer was used to select random numbers between 1 and 54. The following numbers were selected:

4, 22, 39, and 42

Therefore, the 4th, 22nd, 39th and 42nd load delivered to the job would be sampled to represent the 850 tons of material.

Sampling from a Roadway: Determine the length and width of a lot. Determine the number of samples required to represent the lot and pick random numbers for length and width. Determine sample locations by multiplying the lot length by a random number and the lot width by a random number. The length is typically measured from the beginning of the lot and the width is typically measured from the centerline or edge of structure.

Example:

Four samples are required for a 4-meter wide pavement subgrade with a lot size determined to be 1000 linear meters. The lot begins at Station 10+000. Use the random

number table in Figure 3 to determine the sample locations.

From the given information:

lot begins at station 10+000

lot ends at station 11+000

length of lot = 1 000 meters

Determine the sample locations:

Using the random number table, obtain two sets of 4 random numbers each.

Set 1 will be used to determine stationing (X) of the samples by multiplying the random numbers by 1 000 meters.

Set 2 will be used to determine the sampling distance from the right edge of pavement (Y) by multiplying the random numbers by 4 meters.

Random numbers chosen from a table are:

Set 1: .13 .69 .59 .88

Set 2: .73 .82 .46 .33

Sample coordinate locations determination:

Sample #1:

$$X = .13 \times 1000 = 130 \text{ meters}$$

$$Y = .73 \times 4 = 2.92 \text{ meters}$$

Sample #2:

$$X = .69 \times 1000 = 690 \text{ meters}$$

$$Y = .82 \times 4 = 3.28 \text{ meters}$$

Sample #3:

$$X = .59 \times 1000 = 590 \text{ meters}$$

$$Y = .46 \times 4 = 1.84 \text{ meters}$$

Sample #4:

$$X = .88 \times 1000 = 880 \text{ meters}$$

$$Y = .33 \times 4 = 1.32 \text{ meters}$$

Sample locations:

Sample #1:

Station 10+000 + 130 meters = Station 10+130 @ 2.92 meters from right edge of pavement

Sample #2:

Station 10+000 + 690 meters = Station 10+690 @ 3.28 meters from right edge of pavement

Sample #3:

Station 10+000 + 590 meters = Station 10+590 @ 1.84 meters from right edge of pavement

Sample #4:

Station 10+000 + 880 meters = Station 10+880 @ 1.32 meters from right edge of pavement

GLOSSARY

Bell Curve	- A symmetrical, bell-shaped curve that approximates the distribution of many random variables.
Borrow	- Material that has been excavated from one area to be used as fill in another.
Sampling Frequency	- The number of samples taken in a certain period of time or for a particular lot size.
Lot	- A given quantity of material that needs to be sampled.
Pill Box	- A container that holds a group of numbered tokens or "pills." The tokens will be numbered consecutively and will usually range from one to some maximum number.
Random	- An equal probability that any one of a group will be selected.
Statistical Analysis	- The systematic collection, analysis and interpretation of numerical data.
Stratified Random Sampling	- The process of taking random samples from sublots.
Sublot	- A portion of a lot that represents a certain quantity of the material from the lot. For example, a 20-ton lot of material could be divided into four, 5-ton sublots.

Random Number Table, Adapted from ASTM D3665

	0	1	2	3	4	5	6	7	8	9
1	0.272	0.519	0.098	0.459	1.000	0.554	0.250	0.246	0.736	0.432
2	0.994	0.978	0.693	0.593	0.690	0.028	0.831	0.319	0.073	0.268
3	0.039	0.449	0.737	0.501	0.960	0.254	0.239	0.474	0.031	0.720
4	0.144	0.695	0.339	0.621	0.128	0.032	0.413	0.617	0.764	0.257
5	0.312	0.138	0.670	0.894	0.682	0.061	0.832	0.765	0.226	0.745
6	0.871	0.838	0.595	0.576	0.096	0.581	0.245	0.786	0.412	0.867
7	0.783	0.874	0.795	0.430	0.265	0.059	0.260	0.563	0.632	0.394
8	0.358	0.424	0.684	0.074	0.109	0.345	0.618	0.176	0.352	0.748
9	0.494	0.839	0.337	0.325	0.699	0.083	0.043	0.809	0.981	0.499
10	0.642	0.514	0.297	0.869	0.744	0.824	0.524	0.656	0.608	0.408
11	0.485	0.240	0.292	0.335	0.088	0.589	0.127	0.396	0.401	0.407
12	0.728	0.819	0.557	0.050	0.152	0.816	0.404	0.079	0.703	0.493
13	0.029	0.262	0.558	0.159	0.767	0.175	0.979	0.521	0.781	0.843
14	0.918	0.348	0.311	0.232	0.797	0.921	0.995	0.225	0.397	0.356
15	0.641	0.013	0.780	0.478	0.529	0.520	0.093	0.426	0.323	0.504
16	0.208	0.468	0.045	0.798	0.065	0.315	0.318	0.742	0.597	0.080
17	0.346	0.429	0.537	0.469	0.697	0.124	0.541	0.525	0.281	0.962
18	0.900	0.206	0.539	0.308	0.480	0.293	0.448	0.010	0.836	0.233
19	0.228	0.369	0.513	0.762	0.952	0.856	0.574	0.158	0.689	0.579
20	0.746	0.170	0.974	0.306	0.145	0.139	0.417	0.195	0.338	0.901
21	0.363	0.103	0.931	0.389	0.199	0.488	0.915	0.067	0.878	0.640
22	0.663	0.942	0.278	0.785	0.638	0.002	0.989	0.462	0.927	0.186
23	0.545	0.185	0.054	0.198	0.717	0.247	0.913	0.975	0.555	0.559
24	0.360	0.349	0.569	0.910	0.420	0.492	0.947	0.115	0.884	0.452
25	0.789	0.815	0.464	0.484	0.020	0.007	0.547	0.941	0.365	0.261

	0	1	2	3	4	5	6	7	8	9
26	0.279	0.609	0.086	0.852	0.890	0.108	0.076	0.089	0.662	0.607
27	0.680	0.235	0.706	0.827	0.572	0.769	0.310	0.036	0.329	0.477
28	0.078	0.444	0.178	0.651	0.423	0.672	0.517	0.660	0.657	0.972
29	0.676	0.830	0.531	0.888	0.305	0.421	0.307	0.502	0.112	0.808
30	0.861	0.899	0.643	0.771	0.037	0.241	0.582	0.578	0.634	0.077

31	0.111	0.364	0.970	0.669	0.548	0.687	0.639	0.510	0.105	0.549
32	0.289	0.857	0.948	0.980	0.132	0.094	0.298	0.870	0.309	0.441
33	0.961	0.893	0.392	0.377	0.864	0.472	0.009	0.946	0.766	0.287
34	0.637	0.986	0.753	0.566	0.213	0.807	0.017	0.460	0.515	0.630
35	0.834	0.121	0.255	0.453	0.376	0.583	0.422	0.371	0.399	0.366

36	0.284	0.490	0.402	0.151	0.044	0.436	0.747	0.694	0.136	0.585
37	0.038	0.814	0.594	0.911	0.324	0.322	0.895	0.411	0.160	0.367
38	0.351	0.283	0.027	0.220	0.685	0.527	0.943	0.556	0.853	0.612
39	0.143	0.384	0.645	0.479	0.489	0.052	0.187	0.990	0.912	0.750
40	0.512	0.056	0.018	0.122	0.303	0.803	0.553	0.729	0.205	0.925

41	0.296	0.705	0.156	0.616	0.534	0.168	0.564	0.866	0.739	0.850
42	0.451	0.536	0.768	0.518	0.481	0.880	0.835	0.734	0.427	0.847
43	0.837	0.405	0.591	0.370	0.104	0.848	0.004	0.414	0.354	0.707
44	0.724	0.153	0.841	0.829	0.470	0.391	0.388	0.163	0.817	0.790
45	0.665	0.825	0.671	0.623	0.770	0.400	0.068	0.440	0.019	0.944

46	0.573	0.716	0.266	0.456	0.434	0.467	0.603	0.169	0.721	0.779
47	0.332	0.702	0.300	0.570	0.945	0.968	0.649	0.097	0.118	0.242
48	0.755	0.951	0.937	0.550	0.879	0.162	0.791	0.810	0.625	0.674
49	0.439	0.491	0.855	0.446	0.773	0.542	0.416	0.350	0.957	0.419
50	0.700	0.877	0.442	0.286	0.526	0.071	0.154	0.988	0.333	0.626

	0	1	2	3	4	5	6	7	8	9
51	0.523	0.613	0.752	0.733	0.528	0.072	0.820	0.929	0.777	0.461

52	0.905	0.182	0.567	0.249	0.227	0.229	0.604	0.304	0.217	0.142
53	0.373	0.120	0.602	0.793	0.692	0.863	0.954	0.873	0.107	0.675
54	0.057	0.953	0.041	0.090	0.223	0.508	0.806	0.438	0.203	0.586
55	0.967	0.040	0.708	0.271	0.189	0.342	0.740	0.801	0.985	0.263

56	0.917	0.715	0.758	0.005	0.666	0.599	0.934	0.100	0.987	0.085
57	0.131	0.646	0.659	0.047	0.051	0.562	0.435	0.731	0.362	0.317
58	0.326	0.605	0.443	0.601	0.386	0.560	0.378	0.172	0.445	0.636
59	0.299	0.106	0.237	0.732	0.796	0.476	0.099	0.804	0.735	0.950
60	0.101	0.055	0.776	0.686	0.171	0.533	0.936	0.095	0.982	0.211

61	0.267	0.598	0.754	0.658	0.274	0.215	0.177	0.218	0.330	0.628
62	0.471	0.102	0.454	0.568	0.963	0.357	0.882	0.507	0.157	0.580
63	0.535	0.881	0.014	0.966	0.958	0.190	0.180	0.759	0.433	0.355
64	0.277	0.458	0.295	0.196	0.772	0.148	0.466	0.291	0.688	0.046
65	0.719	0.167	0.181	0.653	0.328	0.070	0.015	0.155	0.631	0.063

66	0.385	0.858	0.713	0.883	0.916	0.084	0.561	0.999	0.379	0.668
67	0.862	0.928	0.822	0.812	0.977	0.395	0.788	0.920	0.673	0.698
68	0.486	0.938	0.757	0.749	0.991	0.219	0.264	0.932	0.898	0.006
69	0.091	0.872	0.959	0.922	0.727	0.811	0.075	0.374	0.133	0.730
70	0.146	0.482	0.930	0.611	0.179	0.011	0.248	0.886	0.344	0.926

71	0.709	0.184	0.390	0.409	0.191	0.117	0.860	0.135	0.406	0.134
72	0.996	0.896	0.760	0.347	0.053	0.372	0.193	0.756	0.565	0.914
73	0.971	0.859	0.147	0.114	0.418	0.889	0.792	0.064	0.652	0.288
74	0.202	0.538	0.026	0.949	0.696	0.008	0.846	0.259	0.415	0.425
75	0.212	0.321	0.778	0.940	0.496	0.231	0.664	0.903	0.473	0.909

	0	1	2	3	4	5	6	7	8	9
76	0.207	0.799	0.487	0.022	0.813	0.891	0.500	0.368	0.725	0.437
77	0.818	0.503	0.906	0.224	0.904	0.892	0.455	0.343	0.924	0.197
78	0.701	0.984	0.174	0.141	0.704	0.908	0.048	0.828	0.997	0.058

79	0.035	0.380	0.001	0.381	0.251	0.497	0.214	0.794	0.552	0.588
80	0.221	0.200	0.587	0.353	0.584	0.270	0.885	0.110	0.956	0.711

81	0.647	0.403	0.530	0.738	0.280	0.457	0.650	0.276	0.661	0.973
82	0.667	0.722	0.327	0.723	0.410	0.635	0.012	0.907	0.316	0.677
83	0.644	0.590	0.021	0.269	0.042	0.062	0.387	0.183	0.964	0.544
84	0.302	0.123	0.116	0.282	0.851	0.256	0.648	0.845	0.782	0.993
85	0.633	0.933	0.331	0.546	0.842	0.016	0.236	0.164	0.923	0.976

86	0.060	0.681	0.683	0.775	0.624	0.955	0.126	0.655	0.919	0.113
87	0.165	0.532	0.431	0.341	0.092	0.244	0.222	0.336	0.034	0.216
88	0.875	0.691	0.383	0.382	0.596	0.301	0.275	0.188	0.868	0.805
89	0.726	0.902	0.252	0.130	0.238	0.398	0.763	0.463	0.615	0.140
90	0.273	0.393	0.285	0.161	0.619	0.865	0.551	0.030	0.571	0.258

91	0.253	0.821	0.600	0.023	0.606	0.849	0.610	0.577	0.082	0.774
92	0.340	0.654	0.173	0.495	0.498	0.992	0.192	0.506	0.751	0.129
93	0.194	0.290	0.592	0.983	0.509	0.998	0.522	0.627	0.741	0.540
94	0.166	0.450	0.210	0.204	0.840	0.826	0.833	0.516	0.965	0.375
95	0.712	0.314	0.033	0.823	0.629	0.939	0.887	0.066	0.743	0.081

96	0.622	0.800	0.710	0.575	0.678	0.465	0.802	0.969	0.150	0.784
97	0.313	0.294	0.897	0.718	0.614	0.876	0.025	0.049	0.620	0.125
98	0.137	0.087	0.003	0.483	0.201	0.209	0.320	0.935	0.447	0.787
99	0.243	0.679	0.844	0.069	0.024	0.543	0.714	0.234	0.505	0.428
100	0.361	0.359	0.230	0.761	0.334	0.149	0.511	0.475	0.854	0.119

REDUCING SAMPLES OF AGGREGATE TO TESTING SIZE

AASHTO T 248



Developed by
FHWA-Multiregional Soils Training & Certification Group
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NOTE

Successful completion of the following training materials, including examination and performance evaluation, are prerequisites for this training package.

◆AASHTO D 3665, Practice for Random Sampling of Construction Materials

◆AASHTO T 2, Sampling of Aggregates

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NOTE

There is no AASHTO or ASTM procedure specifically designed for reducing the size of soil samples. This procedure is appropriate to use for that purpose; therefore, it is included in this training manual.

REDUCING SAMPLES OF AGGREGATE TO TESTING SIZE

Aggregates are a major component in highway construction. They are used in all phases from base construction, pavement and structural mix, granular shoulders, and granular surfacing, as well as, erosion control. In order to ensure the aggregate performs as intended for the specified use, a variety of tests must be performed on the aggregate. These samples must be representative of the aggregate selected for use and should be obtained by appropriate methods as described in AASHTO T 2.

The field samples of aggregate must generally be reduced to an appropriate size for testing to determine physical characteristics, such as, sieve analysis (gradation), soundness, hardness, etc. The methods described in this text are intended to minimize variations in aggregate characteristics between the smaller test samples and the larger field samples.

Several methods of sample reduction will be described. The technician must be sure to use the appropriate technique dependent on such factors as aggregate size and moisture content.

The reduction methods include:

- ❖ Method A - Mechanical Splitter
- ❖ Method B - Quartering
- ❖ Method C - Miniature Stockpile

In some circumstances, reducing the field sample prior to testing is not recommended. Substantial differences may unavoidably occur during sample reduction (i.e., in the case of an aggregate having relatively few large size particles in the sample). These few particles may be unequally distributed among the reduced size test samples. If the test sample is being examined for certain contaminants which occur as a few discrete particles in a small percentage, the reduced test sample may not be truly representative of the total aggregate. In these cases, the entire original field sample should be tested.

Failure to carefully follow the procedures in these methods of sample reduction may result in providing a nonrepresentative sample for subsequent testing, resulting in inaccurate test results, and ultimately, failure of the aggregate to perform as intended.

SUMMARY OF SAMPLE REDUCTION

Aggregate and other materials sampled in the field need to be reduced to appropriate sizes for testing. It is, therefore, necessary to reduce field samples while minimizing the chance of variability during handling. In some instances a few particles on a given sieve might affect a gradation significantly enough to alter an interpretation of the field sample and subsequently the compliance of the material with specifications.

The appropriate field sample reduction method is dependent chiefly on the nominal maximum size of the aggregate, the amount of free moisture in the sample, and the equipment available.

The glossary at the back of this section should be read thoroughly before proceeding with sample reduction

The following chart should be used in selecting the appropriate reduction method for the aggregate to be tested.

Mechanical Splitter	Quartering	Miniature Stockpile
Fine Aggregate - Air Dry	Fine Aggregate - Free Moisture on Particle Surface	Fine Aggregate - Free Moisture on Particle Surface
Coarse Aggregates	Coarse Aggregates	Coarse Aggregates
Combined Aggregates	Combined Aggregates with Free Moisture on Particle Surfaces	Not Appropriate for Combined Aggregates

Table 1

COMMON SAMPLE REDUCTION ERRORS

- ▶ Failure to obtain a field sample using the methods and guidelines given in AASHTO T 2.
- ▶ Failure to select proper method for sample reduction based on aggregate moisture content.
- ▶ Failure to uniformly distribute the field sample from edge to edge while placing it in the hopper or pan prior to pouring it through the chutes when using a mechanical splitter.
- ▶ Failure to, when using a mechanical splitter, control the rate at which the materials are poured through the chutes such that the material is free flowing into the receptacle pans below. This includes using a hopper or straight-edged pan that, per AASHTO T 248, has a width equal to or slightly less than the overall width of the assembly of chutes.

- ▶ Failure to use or set mechanical splitters to meet the applicable requirements for number of chute openings and chute width.

Common Sample Reduction Errors - continued

- ▶ When using the quartering method or miniature stockpile method, failure to mix the sample thoroughly by turning the entire sample over three times.
- ▶ When using the quartering method, failure to brush the cleared spaces clean of fines after removing the two diagonally opposite quarters from the flattened field sample.
- ▶ When using the miniature stockpile method, failure to obtain the five (minimum) increments of material from random locations in the miniature stockpile. Do not take all five samples from the same location.

SAMPLE REDUCTION - METHOD A (MECHANICAL SPLITTER)

Before beginning any procedure, you must first assemble all the equipment needed to perform the test.

Apparatus (Mechanical Sample Splitter)

- ▶ The mechanical sample splitter must have an even number of equal width chutes, not less than eight for coarse or combined aggregate, or twelve for fine aggregate.
- ▶ The chutes must discharge alternately to each side of the splitter.
- ▶ For coarse and combined aggregates the minimum width of the individual chutes shall be approximately fifty percent larger than the largest size particle in the sample to be reduced.
- ▶ For dry fine aggregate in which the entire sample will pass the 9.5 mm (3/8 in.) sieve, the minimum width of the chutes shall be at least fifty percent larger than the largest particles in the sample with a maximum width of 19 mm (3/4 in.).
- ▶ The splitter must be equipped with at least two receptacles (catch pans) to hold the two halves of the sample during splitting.
- ▶ It shall also be equipped with a hopper or straight-edge pan with a width equal to or slightly less than the overall width of the assembly of chutes, by which the sample may be fed at a controlled rate into the chutes.
- ▶ The splitter and accessories shall be designed to allow the sample to flow smoothly without restriction or loss of material.

NOTE

Mechanical splitters are commonly available in sizes adequate for material having the largest particle size not over 37.5 mm (1½ in.).

Sample Preparation

Using the mechanical splitter to reduce a fine aggregate sample, the aggregate should be in an air dry condition. The entire sample may be dried to at least a saturated surface dry

condition using temperatures that do not exceed those specified for any of the tests intended to be performed on the material.

If the damp, fine aggregate sample is too large to efficiently dry in this manner, a preliminary split may be performed using a mechanical splitter with chute openings no smaller than 37.5 mm (1½ in.). Reduce the sample to not less than 5000 g and dry this sample. Reduce the dried sample using a mechanical splitter with individual chute openings not to exceed 19 mm (¾ in.) to the required test sample size(s).

When reducing a coarse aggregate by mechanical splitting, the sample may be reduced in a damp condition taking care that any fine particles adhering to the chutes are brushed into the catch pans. Samples containing excess water should be allowed to drain before reduction is attempted.

Combined aggregates may also be reduced in a damp condition, as long as the aggregate flows freely through the chute openings without plugging and any small particles adhering to the chutes are brushed into the catch pans.

When practical, allow all samples to attain an air dry condition before using a mechanical splitter.

NOTE

If the field sample was originally collected in two or more increments (separate sacks containing material from different parts of the same stockpile), then the separate increments must be thoroughly mixed together to form one homogenous field sample. Mixing can be done using an adequate sample splitter or by mixing the sample with a shovel as detailed later in the section describing the quartering method procedure.

Reduction Procedure

Place the original sample, or portion thereof, in the hopper or pan and uniformly distribute it from edge to edge being sure the sample appears homogenous (well-blended). Carefully introduce the sample into the chutes in a manner to allow the aggregate to flow freely through the openings and into the catch pans. Continue this procedure until the entire large sample has been halved, being careful that catch pans do not overflow.

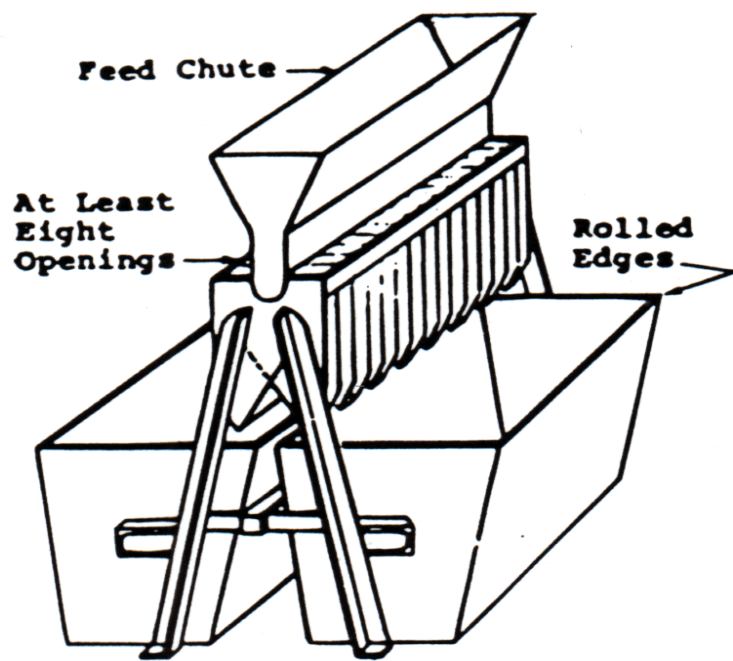
Remove the catch pans and set aside. Continue splitting the other half into quarters. Follow this procedure, being sure to split entire increments, until the desired test sample size is obtained. Retain the unused material until all desired tests are performed in case a retest is needed.

The mechanical splitter method is the preferred method of sample reduction and should be

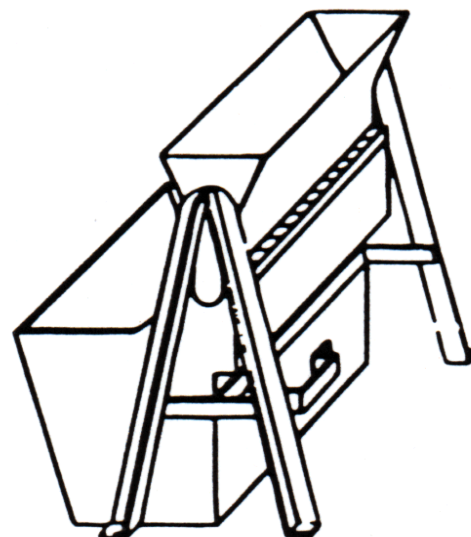
used when practicable. Mechanical splitters are commonly available in sizes adequate for aggregates with particle sizes up to 37.5 mm (1½ in.).

NOTE

Sometimes a significant amount of fines may be lost in the splitting process if the sample is extremely dry and the action of pouring the sample through the splitter chutes creates a large dust cloud, suspending the fines in the air above the splitter. If this is a serious concern, then add a small amount of water to the original sample and mix thoroughly before splitting the sample. The extra moisture will prevent many of the fines from becoming suspended in the air and drifting off. Remember to not add so much water that the moisture content ends up being at or greater than the SSD condition, in which case the mechanical splitting method would no longer be valid. In any case, be sure to perform the splitting procedure in a well-ventilated area while wearing a suitable dust mask (one which is designed to protect against silica dust) or injury to the lungs, over time, may result.

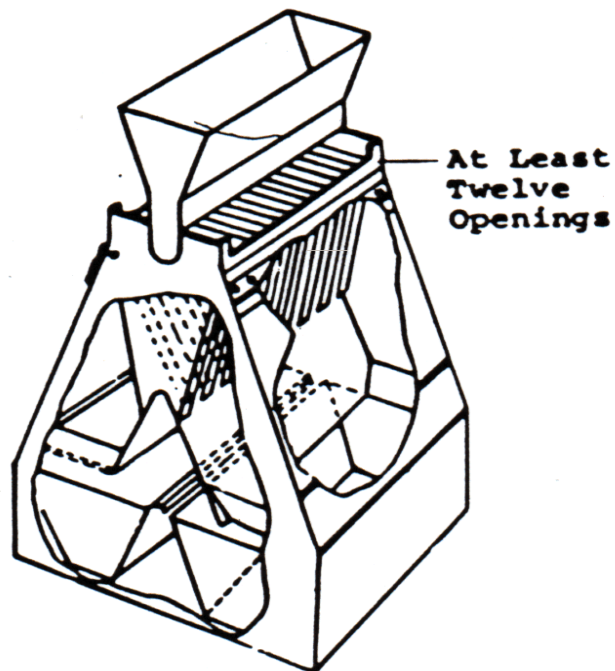
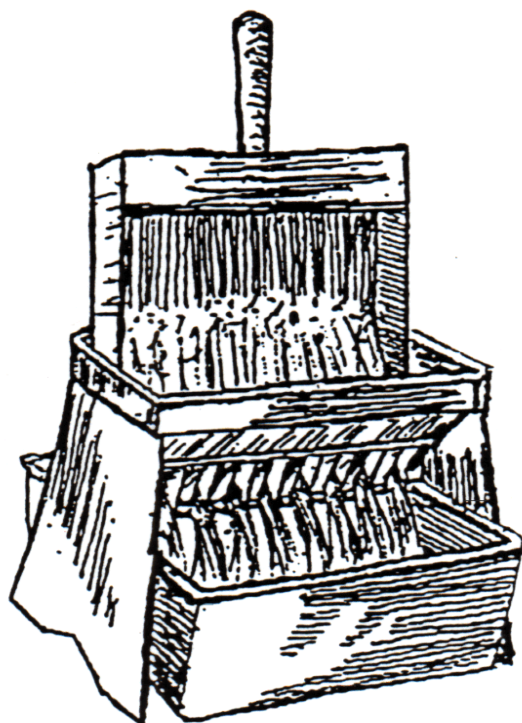


Riffle Sample Splitter



**Riffle Bucket and
Separate Feed Chute Stand**

(a) Large Riffle Samplers for Coarse Aggregate.



NOTE—May be constructed as either closed or open type. Closed type is preferred. (b) Small Riffle Sampler for Fine Aggregate.

FIGURE 1 Sample Splitters

MECHANICAL SAMPLE SPLITTER



Mechanical Splitter



Sample in Splitter



Sample Being Split

SAMPLE REDUCTION - METHOD B (QUARTERING)

Apparatus

The following are the apparatus needed to perform Method B.

- ▶ Straight-edged scoop.
- ▶ Flat-edged shovel or trowel.
- ▶ Broom or brush.
- ▶ Alternate method only - canvas blanket measuring approximately 2 m by 2.5 m (6 ft. X 8 ft.).

Sample Preparation

Fine aggregate must be in a moist condition to use Method B - quartering, to reduce the sample.

The material should be damp enough to allow it to stand in an almost vertical face.

Coarse aggregate may be either damp or dry when using Method B. ***(Method A is the preferred sample reduction method for coarse aggregates).***

Combined aggregates must be in a moist condition to reduce the sample by Method B, again able to stand in an almost vertical face.

Reduction Procedure

Place the original sample on a hard, clean, level surface. Mix the material thoroughly by turning the entire sample over with the shovel three times. With the last turning, shovel the entire sample into a conical pile by depositing each shovelful on top of the preceding one. Carefully flatten the conical pile to a uniform thickness and diameter by pressing down the apex with the shovel so that each quarter section of the resulting pile will contain the material originally in it. The pile diameter should be approximately four to eight times the thickness.

Divide the flattened pile into four equal quarters with the shovel or trowel. Remove two diagonally opposite quarters, including all fine material. Brush the cleared spaces clean. Successively mix and quarter the remaining material in the same fashion as the original sample. Continue this process until the desired quantity is obtained.

Save the unused portion of the original field sample until all testing is completed in case a retest is needed.

METHOD B - ALTERNATIVE

As an alternative to Method B, when the floor surface is uneven, the field sample may be placed on a canvas blanket and mixed with a shovel, or by alternatively lifting each corner of the blanket and pulling it over the sample toward the diagonally opposite corner causing the material to be rolled. Flatten and divide the pile as described in Method B, or if the surface beneath the blanket is too uneven, insert a stick or pipe dividing the pile into two equal parts. Remove the stick leaving a fold in the canvas between the sample halves. Slide the stick under the canvas blanket again at a right angle to the first division and dissecting the two halves of the sample through their centers. Lift the stick evenly from both ends dividing the sample into equal quarters. Remove two diagonal parts including the fine material and clean the area. Successively mix and quarter the remaining material until the desired sample size is obtained.

NOTE

The quartering method is fairly time intensive and thus is generally used in situations where an adequate mechanical splitter is unavailable. Diligence and care is required to ensure that the samples obtained by quartering remain representative of the entire field sample.

METHOD B



Mix by Forming New Cone



Flatten Cone



Divide Sample Into Quarters

Method B



**Stick Placed Under
Flattened Sample**



Sample Divided in Half



Sample Divided Into Quarters

SAMPLE REDUCTION - METHOD C (MINIATURE STOCKPILE)

APPARATUS

The equipment needed to reduce an aggregate sample using Method C includes the following items.

- ▶ Straight-edged scoop
- ▶ Shovel or trowel (for mixing the aggregate)
- ▶ Small sampling thief, small scoop, or spoon

Sample Preparation

The miniature stockpile method must only be used when reducing a sample of fine aggregate. The sample must be in a moist condition before performing this method and remain damp during the performance.

Reduction Procedure

This method is for damp, fine aggregate only.

Place the field sample on a hard, clean, level surface where there will be no loss of material or contamination. Mix the sample by turning the entire sample over three times with a shovel. With the last turning, shovel the entire sample into a conical pile by depositing each shovelful on top of the preceding one. If desired, the conical pile may be flattened to a uniform thickness and diameter by pressing on the apex of the conical pile with the shovel.

Obtain a sample for each test to be performed by selecting at least five increments of material at random locations from the miniature stockpile using a sample thief, small scoop, or spoon.

MINIATURE STOCKPILE



Miniature Stockpile



Taking One of at Least

Five Samples

GLOSSARY

**Nominal Maximum
Size**

- The largest sieve size listed in the applicable specification upon which any material may be retained.

NOTE

Occasionally the largest particles in a material may be smaller than the nominal maximum size as defined and still be in specification compliance. Sample size and reduction method may be revised to reflect the material to be tested.

INSTRUCTOR'S NOTE

Refer to state specification for definition of nominal maximum size by material type and definition of Saturated Surface Dry (SSD).

**Saturated Surface
Dry (SSD)**

- A coarse aggregate is considered to be in a saturated surface dry condition when there is no free moisture present, but the aggregate is in a nonabsorbent state. In other words, the aggregate has all the moisture it can absorb and surface of the aggregate is dry.

Air Dry

- When the aggregate appears to be dry, but still has some absorbed moisture in its pore structure.

Fine Aggregate

- Aggregate which has a nominal maximum size of the 4.75 mm (No. 4) sieve or smaller.

Coarse Aggregate

- Aggregate which is predominately larger than the 4.75 mm (No. 4) sieve.

**Combined
Aggregate**

- Aggregate which has a blend of both coarse and fine particles.

LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOILS

AASHTO T 265



Developed by
FHWA Multi-regional Soils Training & Certification Group

August 1999

NOTE

There are no prerequisites to this training package.

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MOISTURE CONTENT OF SOIL

Soil that is not completely dry contains water. Everything that identifies soil properties for the construction process revolves around moisture content. It is important to know the percentage of water in a soil in order to perform several tests that identify a soil's engineering properties. Moisture content is a factor in determining Atterberg Limits (Plastic Limit, Shrinkage Limit, Liquid Limit) and Moisture-Density Relationships. During the construction process, it is important to know the moisture content of a soil in order to properly relate test results to the field condition of the soil. The correct moisture content is needed to achieve maximum compaction and to allow stabilizing or modifying chemicals (e.g., cement and lime) to work. Excess quantities of water will lead to failing soil foundations, embankments and base courses. In order to determine if a soil foundation has been adequately compacted, it is necessary to know its moisture content. Adequate compaction can only be achieved if a soil is very close to its optimum moisture content (point at which, under standard compaction effort, a soil can be compacted to maximum unit mass). The moisture content of a soil also influences the processes to be used to excavate it, consolidate it, aerate it, and determine its gradation.

The moisture content of a soil refers to the quantity of water it contains. In soil mechanics, moisture content is always expressed as a percent by dry mass. The reason for expressing moisture content in terms of dry mass is based on the idea of solid soil particles remaining relatively constant in mass and volume. Thus the basic structure of the soil remains basically constant. However, the mass changes as the voids between the particles fill with water or lose water. Therefore, the wet unit mass of a soil mass changes as the moisture content changes. In nature, this variability of water content in the pores (voids) tends to be seasonal. Using the fixed dry mass, instead of the variable wet mass provides a stable number on which to judge soil characteristics.

There are four different types of soil moisture:

- ◆ Gravitational - Water that is free to move under the influence of gravity. For in-place soils, this means water at and below the ground water table and is often referred to as ground water.
- ◆ Capillary - Water held by capillary action in the soil pores (interconnecting voids between particles), also called capillaries. Water is at zero pressure at the groundwater level (phreatic surface). Because water has a stronger attraction to solid surfaces than to air, water rises at its boundary and in a narrow tube (capillary action). [A common example of capillary action is the meniscus you see in a soda straw or a hydrometer jar.] Capillary action causes water to be under pressure below the phreatic surface and in tension above. The lifting of water in a narrow (capillary) tube is referred to as surface tension. The raising of water level in a capillary tube is in direct contradiction to gravity. Capillary water is not free water, because it is weakly bound by surface tension action.

- ◆ Hygroscopic - Water that forms a film around the individual soil particles when the soil is exposed to the humidity in the air. The amount of hygroscopic moisture in a soil will vary directly with the humidity. For any soil, the higher the humidity, the higher the percent hygroscopic moisture will be, until the soil and humidity reach equilibrium. Hygroscopic moisture is the amount of moisture in air-dried soil. Hygroscopic moisture can be driven off by oven drying to constant mass; however, as it cools the soil will pick up hygroscopic moisture from the air unless the dried soil is protected while cooling.
- ◆ Interstitial - Loosely bonded water contained within the internal structure of soil particles.

SUMMARY OF TESTING

The test method used to determine the percentage of moisture in a soil is a simple procedure. First, determine the wet mass of the soil specimen (weigh it). Then, dry the soil using an oven. Then weigh the dried soil and repeat the drying process until the mass of the dried soil stops changing (constant mass). That is all there is to the procedure. Finally you perform calculations to determine the percent of moisture removed from the soil (the moisture content).

TYPICAL TEST RESULTS

Naturally occurring soils usually have a moisture content in the range of 5 - 40%. It is possible (although unlikely) to obtain a moisture content as high as 100% or greater. This seemingly impossible number is caused by the determination of moisture content in terms of dry mass. Extremely high moisture contents can only be reasonable if they occur in a highly absorptive soil, such as a soil with a high percentage of organic material. Extremely low moisture contents (i.e., below 5%) are most often indicative of testing error, unless the material is from an extremely arid environment.

In order to ensure that your test results are valid, it is critical to always perform the test exactly as the procedure intends. Testing errors invalidate results.

COMMON TESTING ERRORS

- ▶ Failure to protect sample or test specimen from exposure to air. This error can result in either dehydration (moisture loss) or hydration (moisture gain) and can occur either before or after drying.
- ▶ Overheating the test specimen. Using too high a temperature to dry the material can drive out interstitial moisture or result in material loss during the drying process. If the temperature is too high, soil particles will expand rapidly and literally bounce out of the drying container.
- ▶ Losing material when a forced air oven is used. The draft can blow fines out of a soil specimen. The specimen should never be placed in the air stream.
- ▶ Failure to dry to real constant mass. The technician must determine how long to leave the material in the oven between successive weighings for constant mass. This decision should be based on the friability of the soil and the overall moisture content and clay content. In general, the higher the moisture content and the higher the clay content, the longer the material must remain in the oven between weighings. If the soil does not remain in the oven long enough between weighings, the soil will falsely appear to be at constant mass, because the material has not had time to lose additional moisture.

COMMON TESTING ERRORS - Continued

- ▶ Weighing inaccuracy caused by placing a too hot container on the balance. Heat waves from the container can cause variations in the balance reading.
- ▶ Placing wet test specimens in oven with almost dry specimens, because dry soil may absorb moisture from wet specimens.
- ▶ Recording the wrong data.
- ▶ Calculation errors.
- ▶ Organic Soils. It can be difficult to obtain accurate moisture contents for soils containing significant amounts of organic material or for soils containing gypsum or other minerals with loosely bound water. Gypsum and other such minerals have a loose chemical bond between the water and soil. High drying temperatures will drive out this moisture, causing it to lose its bond and will chemically alter the material. Because the moisture used for construction purposes is based on free water not bonded water, the inclusion of bonded water in the moisture content will not be accurate. High drying temperatures can also destroy organic matter, causing loss of mass. When this occurs the loss of organic mass is counted as water loss causing the resulting moisture content not to be accurate.

TEST METHODOLOGY

Before beginning any procedure, you must first assemble all the equipment you will need to perform the test. To determine the moisture content of a soil specimen, you will need the following.

- ◆ Balance - conforming to AASHTO M23
- ◆ Oven capable of maintaining temperature off $110 \pm 5^{\circ}\text{C}$ ($230 \pm 9^{\circ}\text{F}$)
- ◆ Drying Containers
- ◆ Soil Sample

Test Specimen

From a soil sample, obtain a representative quantity to use as a test specimen. When obtaining the test specimen, be sure to keep it from drying out before it is used for testing.

Use the following table to determine the size of the test specimen.

Maximum Particle Sieve Size	Minimum Mass of Test Specimen, g
0.425-mm (No. 40)	10
4.75-mm (No. 4)	100
12.5-mm (1/2- inch)	300
25.0-mm (1 inch)	500
50-mm (2-inch)	1000

Procedure

1. Turn on the oven and allow its temperature to stabilize at 110°C (230°F).

NOTE

For soils containing organic, turn the oven to 60°C (140°F). If your oven cannot maintain this temperature, dry the soil using vacuum desiccation at a pressure of 10 mm Hg and at a temperature not lower than 23°C (73°F).

2. Determine the mass of the empty container and cover. Record the mass.
3. Place the wet test specimen in the drying container. Cover it immediately. Then determine the mass of the covered container and test specimen. Record the mass of the wet specimen, container and cover.
4. Remove the lid and immediately place the drying container holding the test specimen in the oven.
5. Allow the test specimen to remain in the oven until it reaches constant mass. Constant mass is that point at which the test specimen has the same mass on two successive weighings. If the test specimen can be allowed to remain in the oven for an extended period (e.g., 15-16 hours or overnight), it is safe to assume that constant mass has been reached. If test results must be obtained quickly, to determine if constant mass has been reached, remove the container and test specimen from the oven. Place the lid back on the container. The drying container must be cool enough to be placed on the balance without causing inaccuracy in the balance reading. Determine the mass of the container, lid, and test specimen. Repeat this step until two successive weighing show no change in mass. Be sure to record the mass at each weighing.

Calculations

1. Subtract the mass of the dried test specimen, container and cover (from Step 5) from the mass of the wet test specimen, container and cover (from Step 3). This will give you the mass of moisture in the specimen.
2. Divide the mass of moisture by the mass of the dried specimen minus the mass of the container and cover.
3. Multiply the dividend obtained in Step 2 by 100. This will give you the percent moisture in the sample.

The calculation steps are represented by the following equation:

$$MC = \frac{(W_w - W_d)}{(W_d - W_c)} \times 100$$

Where:

W_w	=	Wet Mass of Specimen, Container and Cover
W_d	=	Dry Mass of Specimen, Container and Cover
W_c	=	Mass of Container and Cover
100	=	Constant to Convert Decimal to a Percent

Example Calculation

Mass of Drying Container and Cover (W_c)	=	15.2 g
Wet Mass of Drying Container, Cover and Test Specimen (W_w)	=	329.6 g
Dry Mass of Drying Container, Cover and Test Specimen (W_d)	=	276.2 g

$$\begin{aligned} MC &= \frac{(W_w - W_d)}{(W_d - W_c)} \times 100 \\ MC &= \frac{(329.6 - 276.2)}{(276.2 - 15.2)} \times 100 \\ MC &= \frac{53.4}{261.0} \times 100 \\ MC &= 0.20459 \times 100 \\ MC &= 20.5\% \end{aligned}$$

Report: Report the percent moisture (MC) to the nearest 0.1%.

GLOSSARY

Atterberg Limits	- Tests designed by A. Atterberg. Used to identify the limits at which a soil passes from a solid, semisolid, plastic, and liquid states. Atterberg Limits are the Plastic Limit, Liquid Limit and Shrinkage Limit. The Plastic Limit and Liquid Limit are used to determine the Plasticity Index.
Absorbed Water	- Water that fills the voids of a soil
Adsorbed Water	- Water that is held in a film on the surface of soil particles.
Capillary Action	- The attraction of water to a surface which causes it to rise against the force of gravity through surface tension.
Constant Mass	- The point at which all free water has been removed from a soil. For the purposes of moisture content testing, constant mass is defined as when a dried soil specimen no longer loses mass in two successive weighings.
Dehydration	- Removal of moisture.
Hydrometer	- A testing device used to measure the specific gravity of a liquid in which particles are either suspended or dissolved.
Hydration	- The incorporation of moisture.
Liquid Limit	- An Atterberg Limit. The point at which a soil moves from a plastic to a liquid state.
Maximum Dry Density	- The dry unit mass of a soil when it is compacted with standard compactive effort and at optimum moisture content.
Maximum Unit Mass	- Same as Maximum Dry Density. The dry unit mass of a soil when it is compacted with standard compactive effort and at optimum moisture content.
Plastic Limit	- An Atterberg Limit. The point at which a soil moves from a semisolid to a plastic state.

GLOSSARY - Continued

Meniscus	-	The curved concave upper surface of a column of liquid in a tube. This concave surface is caused by surface tension. (Refer to Capillary Action.)
Moisture-Density Relationships	-	The interrelationship between density and changing moisture contents in a soil.
Optimum Moisture Content	-	The percent of free moisture at which a soil can reach its maximum density with standard compactive effort.
Organic	-	Vegetable matter included in a soil.
Phreatic Surface	-	Ground water elevation.
Shrinkage Limit	-	An Atterberg Limit. The point at which a soil changes from a solid to a semisolid.
Soil Mechanics	-	The study of engineering properties and behavior of soils.
Surface Tension	-	The lifting of water against gravity in a narrow (capillary) tube.

DRY PREPARATION OF DISTURBED SOIL AND SOIL AGGREGATE SAMPLES FOR TEST

AASHTO T87



Developed by
FHWA Multi-Regional Soils Training & Certification Group

August 1999

NOTE

Successful completion of the training materials, including examination and performance evaluation, for the following are prerequisites for this training package.

- ◆AASHTO T265, Laboratory Determination of Moisture Content of Soils
- ◆AASHTO T 248, Reducing Field Samples of Aggregates to Testing Size

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SOIL PREPARATION

Soil samples received from the field vary widely in terms of moisture content and soil mass. Some are very plastic and stick together firmly; others are loose and friable. Some materials contain a high percentage of aggregates. Many contain aggregates too large to fit into the testing equipment.

Each test designed to identify a soil's properties has certain requirements for the test specimen. Some tests exclude aggregates; others are performed only on a portion of the material (e.g., that portion passing the 0.425 mm [No. 40] sieve). Some require the soil to be at a specified moisture content. Therefore, before most laboratory tests are performed on a soil sample, it must undergo basic preparation.

In order to ensure test results that reflect the true characteristics of the in situ material from which the sample is taken, it is critical that soil be properly prepared. Valid test results can only be obtained from:

- Representative, Properly Protected Samples
- Properly Prepared Test Specimens
- Standard Test Protocols

DRY PREPARATION

The purpose of dry preparation is to prepare a sample for an individual test by reducing the sample to its individual particles without breaking down these particles. Dry preparation is performed on both soils and soil aggregates. For testing purposes, soils are those materials which pass the 2.00 mm (No. 10) sieve. Individual particles retained on the 2.00 mm (No. 10) sieve are considered aggregates. A soil aggregate is a material containing any combination of these two particle sizes.

SUMMARY OF TESTING

To prepare soil for testing, you first dry the sample in an oven. Before putting the sample in the oven to dry, break up any large clods of soil and spread the material evenly across the bottom of the pan. If the material layer is not uniform in thickness or large clods are present, the material may not dry uniformly, resulting in nonrepresentative test results. Large clods are also very difficult to pulverize, which can cause your gradation results to be inaccurate. Then, pulverize the material into individual particles. Next, separate the soil and aggregate fractions of the sample by pouring it over the 4.75 mm (No. 4) or 2.00 mm (No. 10) sieve, as required by the individual test procedure to be performed. You may then separate the sample into additional specific fractions based on other sieve sizes, depending again on which tests are to be performed. Record the dry mass of material passing each sieve and determine the percent by mass for each sieve on the 2.00 mm (No. 10) and larger sieves. Finally, you will reduce each fraction to the quantity required for the tests to be performed.

COMMON PROCEDURAL ERRORS

- ▶ Improper drying
- ▶ Incorrect mass
- ▶ Failure to pulverize to individual particle size
- ▶ Using the wrong sieves
- ▶ Using sieves that are damaged, clogged, etc.
- ▶ Reducing particle size during pulverization, especially critical for brittle particles (e.g., mica and shell)
- ▶ Loss of material

NOTE

Be careful not to lose particles during the preparation process. Loss of material will change the representative nature of the sample and may cause invalid test results.

METHODOLOGY

Before beginning the preparation of the material, you must dry the material at no more than 60°C (140°F). (Some materials [e.g., materials containing bitumen] require drying in air, because oven temperatures will degrade the material. Dry the material to constant mass in accordance with AASHTO T 265.

Before beginning to prepare the dried sample, assemble all the equipment you will need. To prepare a sample for testing, you will need:

- ◆ Balance conforming to the requirements of AASHTO M 231.
- ◆ Sieves
 - 50.0 mm (2 inch)
 - 19.0 mm (3/4 inch)
 - 4.75 mm (No. 4)
 - 2.00 mm (No. 10)
 - 0.425 mm (No. 40)
 - Others as required for specific tests
- ◆ Pulverizing Apparatus
 - Mortar and rubber-covered pestle
 - Power driven rubber-covered muller
 - Revolving drum with rubber-covered rollers
- ◆ Riffle Sampler or Sample Splitter meeting the requirements of AASHTO T 248
- ◆ Assorted Pans for drying and holding the material during preparation

SAMPLE

Refer to Figure 1 for sieve size and representative portion needed for tests when a coarse aggregate gradation is required.

Refer to Figure 2 for sieve size and representative portion needed for specified procedures.

Diameter of Largest Particle, mm (in.)	Minimum Sample Size
9.5 mm (3/8 in.)	0.5 kg
25 mm (1 in.)	2.0 kg
50 mm (2 in.)	4.0 kg
75 mm (3 in.)	5.0 kg

Figure 1: Minimum Sample Size for Soils Containing Aggregate

AASHTO PROCEDURE	TITLE	PREPARED MATERIAL NEEDED FOR TEST
T 88	Particle Size Analysis of Soils	<ul style="list-style-type: none"> *Sandy Soils - 110 g (Passing 2.00 mm) *Silty or Clay Soils - 60 g (Passing 2.00 mm) <li style="padding-left: 40px;">Material Retained on 2.00 mm - <li style="padding-left: 40px;">See Figure 2 for Sample Size.
T 89	Determining the Liquid Limit of Soils	<ul style="list-style-type: none"> *Method A - 100 g (Passing 0.425 mm) *Method B - 50 g (Passing 0.425 mm)
T 90	Determining the Plastic Limit and Plasticity Index of Soils	20 g (Passing 0.425 mm)
T 99	The Moisture Density Relations of Soils Using a 2.5 kg Rammer and a 305 mm Drop	<ul style="list-style-type: none"> *Method A - 3 kg (7 lb) (Passing 4.75 mm) *Method B - 7 kg (16 lb) (Passing 4.75 mm) *Method C - 5 kg (11 lb) (Passing 50 mm, Retained on 4.75 mm, & proportioned by mass on 19 mm) *Method D - 11 kg (25 lb) (Passing 50 mm, Retained on 4.75 mm, & proportioned by mass on 19 mm)
T 100	Specific Gravity of Soils	<ul style="list-style-type: none"> *Volumetric Flask - 25 g (Passing 2.00 mm) *Stoppered Bottle - 10 g (Passing 2.00 mm)

Figure 2: Minimum Particle Size and Sample Size for Soil or Soil Aggregate Samples

PROCEDURE

1. Place the sample in the drying pan and break up large clods of soil.
2. Spread the material in an even layer across the bottom of the pan.
3. Dry the sample to constant mass in accordance with AASHTO T 265.
4. Select a pulverization method.



Mortar and Pestle



Drum Pulverizer



Disk Pulverizer



Jaw Crusher

5. Pulverize the material until the sample is reduced to individual particles. Do not fracture individual particles. Do not lose any particles during the process.
6. Determine the mass of the prepared sample and record.
7. Separate the sample on the 2.00 mm (No. 10) sieve.



Pouring Sample On Nest of Appropriate Sized Sieves

NOTE

You may separate the material on the 4.75 mm (No. 4) sieve instead of the 2.00 mm (No. 10) sieve. When you use this option, you must repulverize the material passing the 4.75 mm (No. 4) sieve until all soil particles pass the 2.00 mm (No. 10) sieve. Be sure to determine the mass of both fractions and record.

8. Determine the mass of material retained on and larger than the 2.00 mm (No.10).
9. Separate the material retained on the 2.00 mm (No. 10) sieve into different fractions using the sieves appropriate for the test to be performed. (Refer to Figures 1 and 2 for sieve designations per test.)
10. Determine the mass of material passing the 2.00 mm (No. 10) sieve. If required by the tests to be performed, separate the material passing the 2.00 mm (No. 10) sieve on the 0.425 mm (No. 40) sieve.
11. Split the sample, in accordance with AASHTO T 248, to the appropriate size for the test to be performed. (Refer to Figure 2 for sample sizes.)



Proportional Sample Splitters for Various Particle Sizes

GLOSSARY

- aggregate** - larger sizes of material usually retained on the 4.75 mm (No. 4) sieve. Gravel and crushed stone are common aggregates.
- brittle** - a material, such as shell, which will break easily during preparation, resulting in reduced particle size.
- constant mass** - used to determine when all moisture has been removed from sample by drying. A sample is dried and weighed repeatedly until there is no more weight loss indicating there is no more moisture to be removed.
- fraction** - a term applied to a portion of a sample resulting from a sieving process.
- friable** - easily crumbled
- in situ** - in its natural or original position
- liquid limit (LL)** - as water is added to a soil, the material reaches a point at which it becomes liquid. The moisture content at this point is the liquid limit.
- non - representative** - a sample which is supposed to, but does not, have the same characteristics as the in situ material from which it was taken.
- particle size** - a soil is composed of many fragments of varying dimensions. When sorted by a sieving process, the soil can be defined by sizes of the fragments related to the sieve size. (e.g., plus 2.00 mm [No. 10], minus 4.75 mm [No. 4], which defines a fragment larger than 2.00 mm and smaller than the 4.75mm.)
- passing** - material fragments which pass through a sieve during sieving operations
- plastic** - material, which when wet, readily holds together and can be molded.
- plastic limit (PL)** - As water is added to a soil, the material reaches a point at which it becomes plastic. The moisture content at this point is called the plastic limit.
- plasticity index (PI)** - The numerical difference between the liquid limit and the plastic limit.

GLOSSARY - continued

- protocol** - standardized methods and sequences of testing developed to ensure reliable results which represent in situ materials
- pulverize** - the process to reduce soil mass into individual particles for testing purposes
- representative** - a sample which possesses the same characteristics as the in situ material from which it was taken.
- retained** - material fragments which do not pass through a sieve during sieving operations, but remain on the sieve surface.
- riffle
splitter** - a device containing chutes on each side which effectively divide a sample into two equal portions
- sieve** - a frame enclosing a wire, cloth, or perforated plate used to separate materials by grain size
- soil** - mineral particles which have been naturally degraded from mass rock
- specific
gravity** - the ratio of the weight in air of a specific volume of material to the weight in air of an equal volume of water, all at the same temperature

SPECIFIC GRAVITY OF SOILS

AASHTO T 100



Developed by
FHWA Multi-regional Soils Training & Certification Group

NOTE

Successful completion of the following training materials, including Examination and performance evaluations are prerequisites for this training package.

- ▶ AASHTO T 265, Laboratory Determination of Moisture Content of Soils
- ▶ AASHTO T 87, Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Test

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SPECIFIC GRAVITY OF SOILS

The specific gravity of a soil is used in almost every equation expressing the phase relationship of air, water, and solids in a given volume of material. It is defined as the ratio of the mass of a given volume of material to an equal volume of water.

$$S_g T_x / T_i = \frac{W_o}{W_o + (W_a - W_b)}$$

Where:

S_g = specific gravity.

W_o = Mass of oven dried soil, in grams.

W_a = mass of pycnometer filled with water at T_x , in grams.

W_b = mass of pycnometer filled with water and soil at temperature T_x , in grams.

T_x = temperature of the contents of the pycnometer when mass W_b was determined, in degrees Celsius.

The term "Solid particles," as used in Geotechnical engineering, is typically assumed to mean naturally occurring mineral particles that are not very soluble in water. Soils of varying mineral content can have a wide range of specific gravities. However, they are typically in the range of 1.40 to 2.80. The specific gravity of some natural soils, as well as materials containing additives (e.g. cement, lime) or water soluble matter (e.g. sodium chloride) may have specific gravities of less than 1 (floats on water) and are not typical of soils used in construction. These materials would require more detailed engineering solutions to make them usable.

SUMMARY OF TESTING

This method covers the determination of specific gravity by means of a pycnometer. When the soil is composed of particles of both larger and smaller than 4.75 mm sieve, the sample shall be separated on the 4.75 mm sieve and the appropriate test method used on each portion. When soil-aggregate materials are tested, the specific gravity shall be the weighted average of the specific gravities of the plus 4.75 mm and the minus 4.75 mm portion. If the specific gravity is to be used for AASHTO T 88 Particle-size Analysis of Soils, it is intended for the specific gravity be performed on the material which passes the 2.00 mm sieve.

NOTE

When material is retained on the 4.75 mm sieve, the specific gravity of that material will be determined by procedures in the Aggregate Technician Training Manual.

This method takes the technician through the calibration of the pycnometer, weighing the soil in the pycnometer, partially filling the bottle with water, distilling the sample by evacuating air from the soil-water mixture, refilling the pycnometer with de-aired water, weighing and completing calculations.

TYPICAL TEST RESULTS

The specific gravity of naturally occurring soils, as defined by this procedure , will range between 1.40 and 2.80.

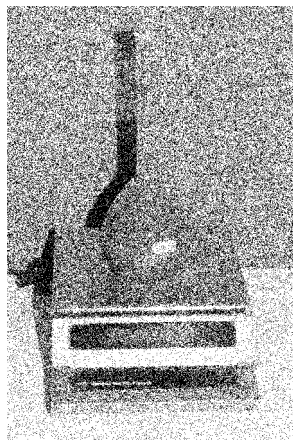
If results outside this range are encountered, the data or sample shall be considered suspect

COMMON TESTING ERRORS

- ▶ Not carefully measuring the temperatures at the time of calibration and testing.
- ▶ Not carefully reading the charts and tables used in this method. It is very easy to misinterpret the data. Read and record, then read again, to verify.
- ▶ Not carefully recording weights that are determined, read-write-reread every time.
- ▶ Losing material (water or soil) from weighed containers.
- ▶ Improper calibration.
- ▶ Not removing air from sample during test.

METHODOLOGY

Equipment



Before beginning any procedure, you must first assemble all the equipment you will need to conduct the procedure. For this procedure you will need the following.

- ▶ Pycnometer - Either a volumetric flask having a capacity of at least 100 mL or a stoppered bottle having a capacity of at least 50 mL. The stopper shall be of the same material as the bottle, and of such size and shape that it can be easily inserted to a fixed depth in the neck of the bottle, and shall have a small hole through its center to permit emission of air and surplus water.
- ▶ Balance-either AASHTO M 231 Class C; 1200 g capacity, readable to 0.01 g for use with the volumetric flask, or AASHTO M 231 Class B; 200 g capacity, readable to 0.001g for use with the stoppered bottle.
- ▶ Oven-Thermostatically controlled drying oven capable of maintaining $110^{\circ}\text{C} \pm 5^{\circ}$. Thermometer-a thermometer covering a range of $0\text{--}50^{\circ}\text{C}$ readable and accurate to 1°C .
- ▶ Desiccator
- ▶ Vacuum pump or Bell Jar
- ▶ Evaporating dish
- ▶ Beaker
- ▶ Spatula

NOTE

When the volumetric flask is used in the specific gravity determination all masses shall be determined to the nearest 0.01 g. When stoppered bottle is used, all masses shall be determined to the nearest 0.001 g.

CALIBRATION OF PYCNOMETER

- ▶ Clean and dry the pycnometer. Weigh the pycnometer and record the mass as W_f .
- ▶ Fill the pycnometer with distilled water at room temperature, weigh and record the mass of the pycnometer and water as W_a .
- ▶ Insert the thermometer into the bottle and measure the temperature of the water, record the temperature as T_i , determined to the nearest whole degree.
- ▶ From the mass W_a determined at the observed temperature T_i , a Table of values of mass W_a shall be prepared for a series of temperatures that are likely to prevail when masses W_b are determined later.

CALCULATIONS FOR PYCNOMETER CALIBRATION

The values of W_a are to be calculated using the following equation.

$$W_a(@ T_x) = \frac{\text{density of water at } T_x}{\text{density of water } T_i} \times [W_a(\text{at } T_i) - W_f] + W_f$$

(See Table 1 for values of relative density of water at various temperatures)

Where:

W_a = mass pycnometer and water, in grams.

W_f = mass of pycnometer, in grams.

T_i = observed temperature of water, in degrees Celsius

T_x = any other desired temperature in degrees Celsius

Temperature, deg. C	Relative Density of water	Correction factor K
18	0.9986244	1.0004
19	0.9984347	1.0002
20	0.9982343	1.0000
21	0.9980233	0.9998
22	0.9978019	0.9996
23	0.9975702	0.9993
24	0.9973286	0.9991
25	0.9970770	0.9989
26	0.9968156	0.9986
27	0.9964541	0.9983
28	0.9962642	0.9980

Temperature, deg. C	Relative Density of water	Correction factor K
29	0.9959761	0.9977
30	0.9956780	0.9974

Table 1 - Relative Density of Water and Conversion Factor **K** for Various Temperatures
SAMPLE

Sieve the sample on the 2.00 mm sieve. The soil to be used in the specific gravity test may be at its natural moisture content or oven-dried. The mass of the sample (oven-dried at 110±5° C) shall be at least 25 g when the volumetric flask is to be used, and at least 10 g when the stoppered bottle is used.

Sample Preparation

- ▶ Samples containing natural moisture.
 - Take a portion of the sample for moisture determination in accordance with AASHTO T 265.
 - Disperse the test sample in distilled water in accordance with AASHTO T 88.
- ▶ When an oven-dried sample is to be used.
 - Dry the sample in accordance with AASHTO T 265. Cool to room temperature, using a desiccator to prevent absorption of hygroscopic moisture. Weigh the sample and transfer to the pycnometer. Add distilled water into the pycnometer in an amount that will provide complete sample coverage. The sample shall then soak for a minimum 12 hours.

Procedure

- ▶ After sample preparation, remove entrapped air by one of the following methods:
 - Subject the sample to a partial vacuum of 13.33 kPa (100 mm) or less absolute pressure: or
 - Boil the sample gently for at least 10 minutes, while occasionally rolling the pycnometer to assist in the removal of air.

NOTE

Subjection of the contents to reduced air pressure may be done either by connecting the pycnometer directly to an aspirator or vacuum pump, or by the use of a bell jar. Some soils boil violently when subjected to reduced air pressure. It will be necessary, in those cases, to reduce the pressure at a slower rate or to use a larger flask.

- ▶ Cool to room temperature.
- ▶ Fill the pycnometer with distilled water to its calibrated capacity.

- ▶ Clean and dry the outside and dry with clean, dry cloth.
- ▶ Determine the mass of the pycnometer and contents, and record.
- ▶ Determine the temperature in degrees Celsius, and record.

CALCULATION OF SPECIFIC GRAVITY

Calculate the specific gravity of the soil in accordance with the following equation:

$$S_g T_x / T_i = \frac{W_o}{W_o + (W_a - W_b)}$$

Where:

S_g = specific gravity.

W_o = Mass of oven dried soil, in grams.

W_a = mass of pycnometer filled with water at T_x , in grams.

W_b = mass of pycnometer filled with water and soil at temperature T_x , in grams.

T_x = Observed temperature of the contents of the pycnometer when mass W_b was determined, in degrees Celsius.

T_i = Calibrated temperature of the contents of the pycnometer when mass W_a was determined, in degrees Celsius

NOTE

Unless otherwise required, specific gravity values shall be based on water at 20°C using the following equation:

$$S_g(T_x / 20^\circ \text{C}) = K \times S_g\left(\frac{T_x}{T_i}\right)$$

Where:

K = a number found by dividing the relative density of water at temperature T_x by the relative density of water at 20° C. See Table 1 for a range of values.

REPORT

- ▶ Sample identification information, such as sample location, depth, classification, etc.
- ▶ Specific Gravity at 20° C and the sieve through which the sample was prepared.

GLOSSARY

- Pycnometer** - A small hand blown glass bottle of known volume, usually 100 mL or less, with a vent in its stopper to allow excess water to leave the bottle when the stopper is inserted.
- Specific Gravity** - The ratio of the mass of a given volume of material to the mass of an equal volume of water at a specified temperature, usually 20° C.
- Volumetric Flask** - A large glass bottle of known volume, usually greater than 500 mL, with an etched calibration line on its stem.
- Bell Jar** - Glass container used for vacuum testing, which is strong enough to resist collapsing.
- Hygroscopic Moisture** - Moisture still remaining in soil after it has been air-dried.
- Entrapped Air** - Air that is trapped within the soil.

PARTICLE SIZE ANALYSIS OF SOILS

AASHTO T 88



Developed by:
FHWA Multi-Regional Soils Training and Certification Group

NOTE

Successful completion of the following training materials, including examination and performance evaluation are prerequisites for this training package.

AASHTO T 87, Dry Preparation of Disturbed Soil and soil Aggregate Samples for Test

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PARTICLE SIZE ANALYSIS OF SOIL

Particle size analysis is used to determine the percentages present of different size particle grains in a soil. This information is usually expressed in terms of percent passing a particular sieve size or percent smaller than a particular particle size. Specifically, the expression, "percent passing," is usually reserved for the 0.075 mm (No. 200) and larger standard sieve sizes. For sizes smaller than a 0.075 mm (No. 200) sieve, the term, "smaller than," is used, especially with respect to clay and colloidal size material. Silt size material is defined as being between 0.074 mm to 0.002 mm in size. Clay size material is smaller than 0.002 mm, but larger than 0.001 mm. Colloids are very small particles, being anything smaller than 0.001 mm.

The particle size analysis provides the technician with some of the information required to classify the soil. Also, it can be used to determine if the material meets construction specifications in terms of a certain range of acceptable "percent passing" values allowed for certain sieves. See Table 1 for an example of one of these gradation (particle size analysis-based) specifications. The gradation shown is a Federal Highway Administration specification, but state and local government agencies and specific projects will generally have gradation specifications of their own for different types of material (e.g., borrow, backfill, embankment). The technician needs to be aware of which specifications apply to the particular project for which the soil is being tested.

Particle size analysis results also can be used to make very rough estimates of the degree of permeability and for soil stabilization mix design and control. Generally the larger the grain size of the soil (the coarser it is), the better it's engineering properties.

Sieve Size	Percent by Weight Passing Designated Sieve (AASHTO T 27 and T 11)
63 mm (2-1/2 in.)	100
50 mm (2 in.)	65 - 100
25 mm (1 in.)	50 - 85
4.75 mm (No. 4)	30 - 50
0.425 mm (No. 40)	0 - 16
0.075 mm (No. 200)	0 - 9

Table 1: Select Borrow Gradation

SUMMARY OF PROCEDURE

This test method is performed on a soil sample prepared as directed in AASHTO T 87, Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Test. Distribution of particle sizes of material retained on the 2.00 mm (No. 10) sieve is performed using a nest of sieves (sieve analysis). A portion of the soil sample passing the 2.00 mm (No. 10) sieve is subjected to a hydrometer analysis and sieve analysis.

The hydrometer analysis is performed on a prepared portion of the material passing the 2.00 mm (No. 10) which is dispersed and placed into a sedimentation cylinder. The sample, previously mixed with dispersing agent and distilled water, is further diluted with distilled water added to the sedimentation cylinder. The sample is allowed to come to a constant temperature, after being placed in a water bath or constant temperature room, before proceeding with the test. After a final period of agitation, the sample is allowed to settle. During the settlement period, measurements of the specific gravity and temperature of the soil sample are made at certain specific time intervals. These measurements are called hydrometer readings. The measurements require corrections before they are used in a formula which yields the percentage of originally dispersed soil remaining in solution. A mathematical equation called Stoke's Law is applied to find the maximum diameter of particles in suspension at the time of any particular reading.

After all hydrometer readings are made, the soil solution is removed from the sedimentation cylinder and washed on a 0.075 mm (No. 200) sieve. The fraction retained on the sieve is then dried and a sieve analysis performed on it. Mathematical calculations are performed and the information provided by the sieve analysis and hydrometer measurements are combined to produce a grain diameter accumulation curve, which is a graphical representation of particle

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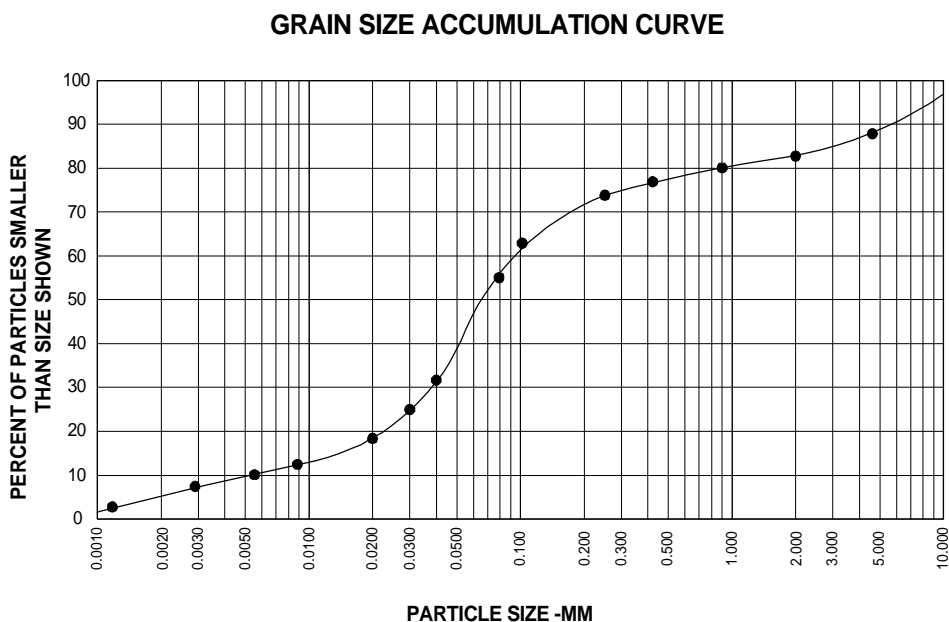


Figure 1 - Grain size Accumulation curve

Soil-T88-2

COMMON TESTING ERRORS

- ▶ Inadequate Dispersion of Soil Sample in Solution. To ensure that adequate dispersion takes place, be sure to adhere carefully to the mixing time requirements and ensure that the dispersion apparatus conforms to the detailed drawings and specification in AASHTO T 88.
- ▶ Inaccurate determination of and/or recording of sample mass.
- ▶ Unnecessary vibration or otherwise unnecessarily disturbing the soil solution in the sedimentation cylinder after final agitation has taken place. You can minimize disturbance by:
 1. Lowering the hydrometer into the sample slowly. Do not let the hydrometer drop into the solution.
 2. Making sure that the hydrometer floats freely in the solution and does not touch the wall of the sedimentation cylinder.
- ▶ Not allowing the soil solution to come to a constant temperature before final agitation and subsequent hydrometer readings.
- ▶ Inaccurate reading of the hydrometer. The hydrometer should be read at the top of the meniscus formed by the soil suspension around its stem, (See Figure 2).
- ▶ Failure to, after dispersing the sample in the mechanical stirring or dispersing apparatus, rinse off the cup and paddles of the apparatus thoroughly enough as you transfer the soil solution to the sedimentation cylinder.
- ▶ Failure to use a fresh solution of dispersing agent (sodium hexametaphosphate). As per AASHTO T 88, the solution should "be prepared frequently (at least once per month), or adjusted to pH of 8 or 9 by means of sodium carbonate."
- ▶ Loss of material when agitating soil in sedimentation cylinder.
- ▶ Failure to wash particles from hand or stopper into sedimentation cylinder.
- ▶ Inaccurate correction factor used.
- ▶ Loss material during sieving and washing.
- ▶ Water pressure too high when washing. Pushes particles through sieve or causes material to splash out.
- ▶ Errors made in calculations.

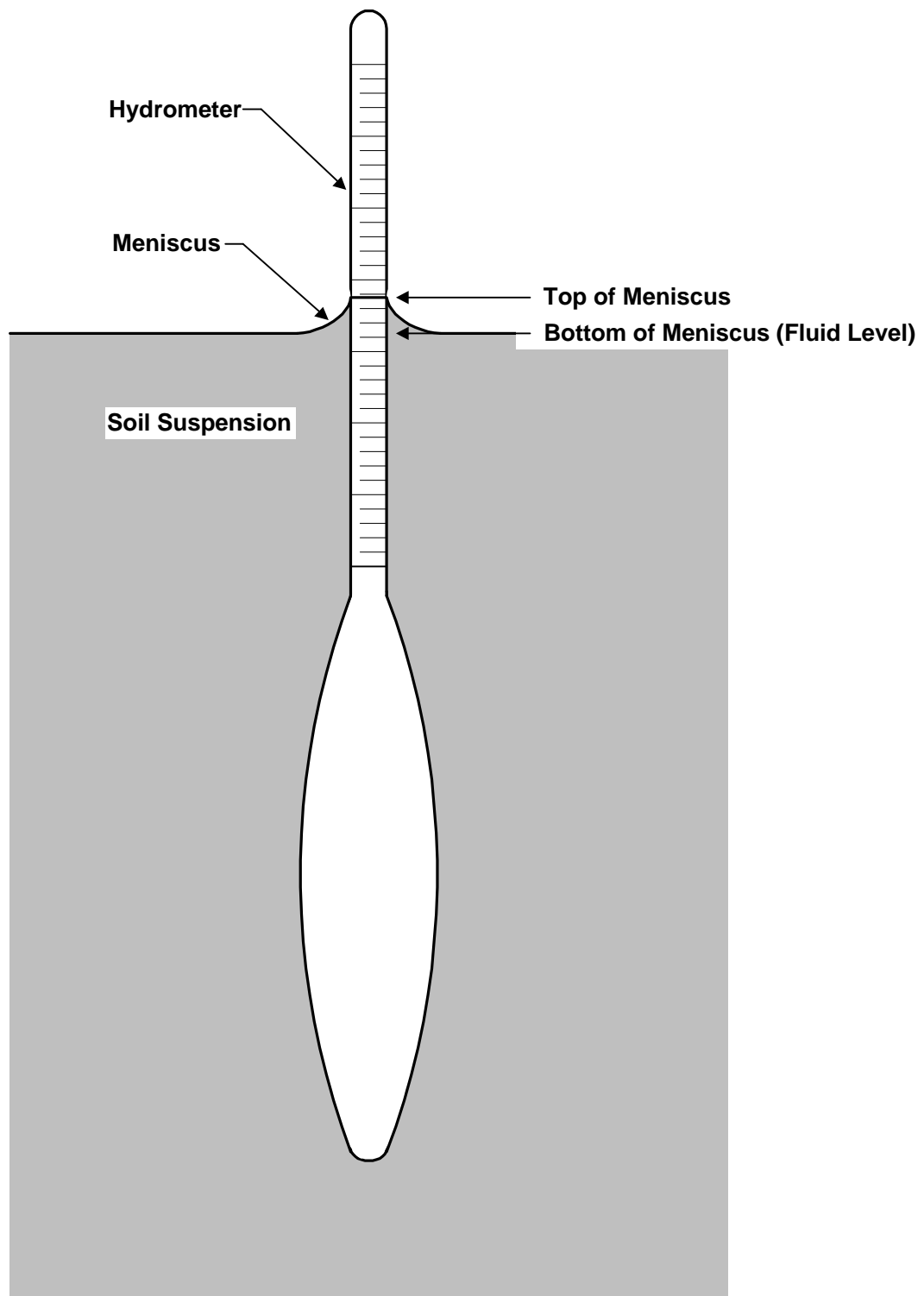


Figure 2 - Hydrometer and Meniscus

TEST METHODOLOGY

Equipment

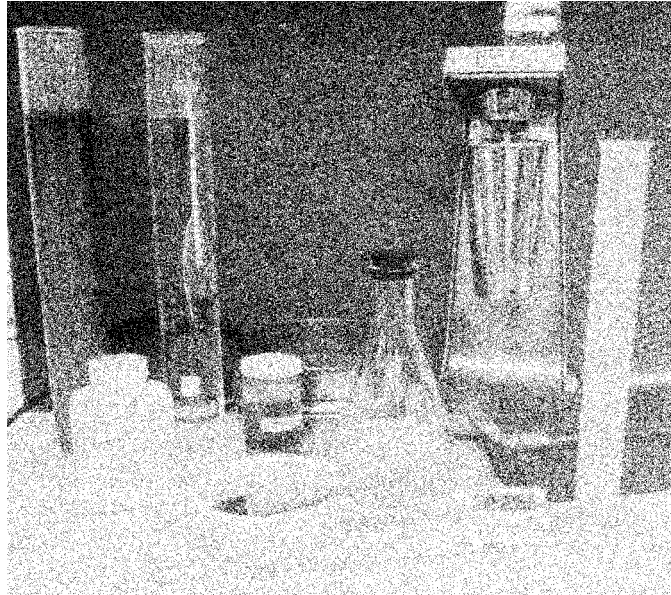


Figure 3 - Hydrometer equipment

Before beginning any procedure, you must first assemble all the equipment you will need to perform the test. You will need the following equipment to perform AASHTO T 88 as shown in Figure 3.

- ▶ Oven-capable of maintaining temperature of $110 \pm 5^{\circ} \text{C}$ ($230 \pm 9^{\circ} \text{F}$).
- ▶ Balance - conforming to the requirements of AASHTO M 231.
- ▶ Drying containers.
- ▶ Mechanically operated stirring apparatus or, alternatively, an air jet type dispersing apparatus, conforming to the drawings, dimensions, and operating characteristics detailed in AASHTO T 88.
- ▶ Hydrometer - An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per liter of suspension, and conforming to the requirements for hydrometers 151H or 152H in ASTM Specifications E 100. Dimensions of both hydrometers are the same, the scale being the only item of difference.
- ▶ Sedimentation cylinders - A glass cylinder approximately 460 mm (18 in.) in height and 60 mm (2-1/2 in.) diameter and marked for a volume of 1000 mL. The inside diameter shall be such that the 1000 mL mark is $360 \pm 20 \text{ mm}$ ($14 \pm 1.0 \text{ in.}$) from the bottom on the inside.

- ▶ Thermometer - A calibrated thermometer readable to 0.5° C (1° F).
- ▶ Sieves - A series of sieves of square mesh woven cloth, conforming to the requirements of AASHTO M 92, Sieves for Testing Purposes. The sieves normally required are as follows in Table 2:

Metric	English
75 mm	3 in.
50 mm	2 in.
25 mm	1 in.
9.5 mm	3/8 in.
4.75 mm	No. 4
2.00 mm	No. 10
0.425 mm	No. 40
0.075 mm	No. 200

Table 2 - Sieve sizes

<p>NOTE</p> <p>The above sieves fulfill the requirements of AASHTO M145 and M147. If required, intermediate sieve sizes like those listed to the right may be used.</p>	Metric	English
	37.5 mm	1-1/2 in.
	19 mm	3/4 in.
	2.36 mm	No. 8
	1.18 mm	No. 16
	0.60 mm	No. 30
	0.30 mm	No. 50
	0.15 mm	No. 100

- ▶ Water bath or constant temperature room - used for maintaining the soil suspension at a constant temperature during the hydrometer analysis. See AASHTO T 88 for detailed drawings, dimensions, and specifications for this equipment.
- ▶ Beaker - A 250 mL beaker.
- ▶ Timing Device - A watch or clock with a sweep second hand.
- ▶ Glass Rod - Suitable for stirring the sample mixture.
- ▶ Wash Bottle or Syringe
- ▶ Distilled water.
- ▶ Sodium hexametaphosphate solution (dispersing agent) - Prepared using distilled water and sodium hexametaphosphate. Add sodium hexametaphosphate to distilled water at the rate of 40 g sodium hexametaphosphate per liter of total solution. AASHTO T 88 specifies

that the solution should be prepared frequently (at least once a month) or its pH adjusted to 8 or 9 by using sodium carbonate.

Sample Preparation

Prepare the test sample using the procedures outlined in AASHTO T 87, Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Test. After initial preparation, weigh a representative portion of the original dried sample. Separate the representative portion into two fractions using a 2.00 mm (No. 10) sieve.

NOTE

AASHTO T 88 allows the use of either the 4.75 mm (No.4) or the 0.425 mm (No.40) sieve as an alternate to using the 2.00 mm (No. 10) sieve for separating the representative portion into two fractions. Although not covered in this text, both alternates are acceptable. The student should consult AASHTO T 88 for further details.

Take care to ensure that the representative portion separated is large enough to yield the following minimum amounts of material to be retained on the 2.00 mm (No. 10) sieve, based on nominal size of the largest particles present:

Nominal Size of Largest Particles		Approximate Minimum Mass of Portion
Metric	English	
mm	in.	kg
9.500	3/8	0.500
25.000	1.000	2.000
50.000	2.000	4.000
75.000	3.000	5.000

Table 3 - Minimum mass of representative portion

Both the fraction (subsample) of the representative portion (hereafter described as "the sample") retained on the 2.00 mm (No. 10) sieve and the fraction (subsample) passing the 2.00 mm (No. 10) sieve now need to be weighed. Weigh the subsample retained on the 2.00 mm (No. 10) sieve to the nearest 0.1 percent of the subsample's mass. This coarse fraction is going to undergo mechanical sieve analysis during which its constituent particles will be separated by size and each size fraction weighed. The same 0.1 percent weighing requirement will also apply to these smaller size fractions.

0.1% x Mass of Subsample = Weighing Precision Required

For example, if the size of the subsample originally retained on the 2.00 mm (No. 10) sieve is 2000 g, then after undergoing the additional mechanical sieve analysis/separation each constituent sieve fraction would be weighed to the nearest 2 g.

$$\frac{0.1\%}{100} \times 2000 = 2\text{g}$$

After it has been weighed, split the subsample passing (finer than) the 2.00 mm (No. 10) sieve using a sample splitter to yield the following smaller test samples:

1. For the hydrometer test:

- a. A sample of approximately 100 g if the soil is sandy.
- or
- b. A sample of approximately 50 g if the soil is silty or clayey.

2. For the hygroscopic moisture determination: At least a 10 g sample.

Mechanical Sieve Analysis of Fraction Retained On 2.00 mm (No. 10) Sieve

The portion of the sample retained on the 2.00 mm (No. 10) sieve is, as described previously, further separated using a series of coarser sieves. These sieves include, but are not limited to, the following sizes:

!	75 mm (3 in.)
!	50 mm (2 in.)
!	25 mm (1 in.)
!	9.5 mm (3/8 in.)
!	4.75 mm (No. 4)

Additional sieves can be used to avoid overloading any one individual sieve or to check how closely a soil conforms to a gradation-based specification requirement. See Table 4 for guidance on how to avoid overloading sieves by limiting the mass of particles on any one sieve to a certain maximum amount. Table 4 is based on the following recommendation, as set forth in AASHTO T 27, Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates:

- For sieves with openings smaller than 4.75 mm (No. 4)), the mass retained on any sieve at the completion of the sieving operation shall not exceed 6 kg/mm² (4 g/in²) of sieving surface. For sieves with openings 4.75 mm (No. 4) and larger, the mass in kg/m² of sieving surface shall not exceed the product of 2.5 x (sieve opening in mm). In no case shall the mass be so great as to cause permanent deformation of the sieve cloth.

Although the sieving can be done by hand, it will in most cases be more efficient to use a mechanical device such as a Rotap or Gilson shaker. The sieving procedure should be done in accordance with AASHTO T 27. Even though we are dealing with soil here (instead of aggregate), the basic sieving procedure and calculations are the same.

After a sufficient period of sieving (as described in detail in AASHTO T 27 under the procedure

section), remove the stack of sieves from the mechanical shaking device (if used), remove the contents of each sieve, weigh and record the weights. The total percentage of material passing each sieve can be calculated based on the original total sample mass and the individual masses retained on each individual sieve size. The following narrative and Figures 4 through 8 illustrate the AASHTO T 27 method, but keep in mind that, for AASHTO T 88, this calculation methodology is used to calculate the percent passing values for the 2.00 mm (No. 10) and coarser sieves only (the hydrometer analysis gives information on finer sieves):

Sieve Size	203 mm Round (A=0.028502 m ²)	305 mm Round (A=0.067012 m ²)	457 mm x 610 mm Rectangular (A=0.301935 m ²)
4.75 mm (No. 4)	330	800	3 590
9.5 mm (3/8 in.)	670	1 590	7 170
12.5 mm (½ in.)	890	2 090	9 440
19.0 mm (¾ in.)	1 350	3 180	14 340
25.0 mm (1 in.)	1 780	4 190	18 870
37.5 mm (1-1/2 in.)	2 670	6 280	28 310
50 mm (2 in.)	3 560	8 380	37 740
63 mm (2-1/2 in.)	^A	10 550	47 550
75 mm (3 in.)	^A	12 560	56 610

^ASieves indicated have less than five full opening and should not be used for sieve testing except as provided in E 5

Figure 4: Maximum Loading Specifications for Individual Sieves
(masses in grams, from AASHTO T27)

Non-Cumulative Method

1. Tare the pan on the scale. Weigh the material retained on each sieve (from top to bottom). After the material from each sieve is weighed, empty the tarred pan and go to the next sieve. Once all the sieves have been weighed, sum the mass of each fraction and record the Total Mass. A table should be used as shown in the example in Table 5.

Sieve Size	Mass	% Retained	% Passing
9.5 mm (3/8 in.)	0.0	0.0	
4.75 mm (No. 4)	96.800	11.700	
2.00 mm (No. 10)	286.500	34.500	
0.850 mm (No. 20)	325.800	39.300	
0.600 mm (No. 30)	65.300	7.900	
0.425 mm (No. 40)	27.100	3.300	

0.180 mm (No. 80)	18.900	2.300	
0.075 mm (No. 200)	6.100	0.700	
Pan	3.300	0.400	
Total	829.800	100.100	

Table 5: Non-Cumulative Method, Steps 1 through 3

2. Calculate the %Retained by dividing the Mass Retained on each sieve by the Total Mass, and multiplying by 100.

$$\% \text{Retained} = \frac{\text{Mass Retained}}{\text{Total Mass}} \times 100$$

For example, from Figure 4 for the 4.75 mm sieve,

$$\% \text{Retained} = \frac{96.8\text{g}}{829.8\text{g}} \times 100 = 11.7\%$$

3. Sum the percentages retained to determine if the total percentage retained equals or nearly equals 100%. If the total is not between 99.7 and 100.3%, an error has been made in weighing, recording or calculations. If the error is not found in the calculations, the fractions will need to be reweighed and recorded again.
4. Calculate the %Passing for each sieve by cumulatively subtracting the percentage retained on each sieve from 100%, beginning with the largest sieve (See Table 6).

Sieve Size	Mass	% Retained	% Passing
9.5 mm (3/8 in.)	0.0	0.0	100.0
4.75 mm (No. 4)	96.8	11.7	88.3
2.00 mm (No. 10)	286.5	34.5	53.8
0.850 mm (No. 20)	325.8	39.3	14.5
0.600 mm (No. 30)	65.3	7.9	6.6
0.425 mm (No. 40)	27.1	3.3	3.3
0.180 mm (No. 80)	18.9	2.3	1.0
0.075mm (No. 200)	6.1	0.7	0.3
Pan	3.3	0.4	
Total	829.8	100.1	

Table 6: Non-Cumulative Method, Steps 4 and 5

5. Continue the cumulative subtraction all the way down through the last sieve (Table 6). The % passing the last sieve should be almost equal to the % retained in the pan.

For example, from Figure 5 for the 2.00 mm sieve,

$$\% \text{Passing} = 88.3 - 34.5 = 53.8\%$$

The calculation for the sieve analysis applies to both coarse and fine aggregate samples. Conventionally, fine aggregate samples are weighed to the nearest 0.1 g. Alternately, coarse aggregate samples are weighed to the nearest 0.01 kg.

Hydrometer and Sieve Analysis of Fraction Passing the 2.00 mm (No. 10) Sieve

Determination of Composite Correction for Hydrometer Reading

There are three errors that must be corrected for when conducting a hydrometer test.

1. **Specific Gravity of Solution:** The equations for percentages of soil remaining in suspension are based on the use of distilled or demineralized water. Since a dispersing agent is used, the resulting liquid will have a specific gravity appreciably greater than distilled water.
2. **Testing Temperature:** Soil hydrometers are calibrated at 20° C (68° F). Testing at any other temperature will produce an inaccuracy.
3. **Meniscus Reading:** Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus due to the opaque nature of the mixture, the readings must be taken at the top of the meniscus.

The amount of correction needed to account for these three errors is known as the composite correction and may be determined as follows.

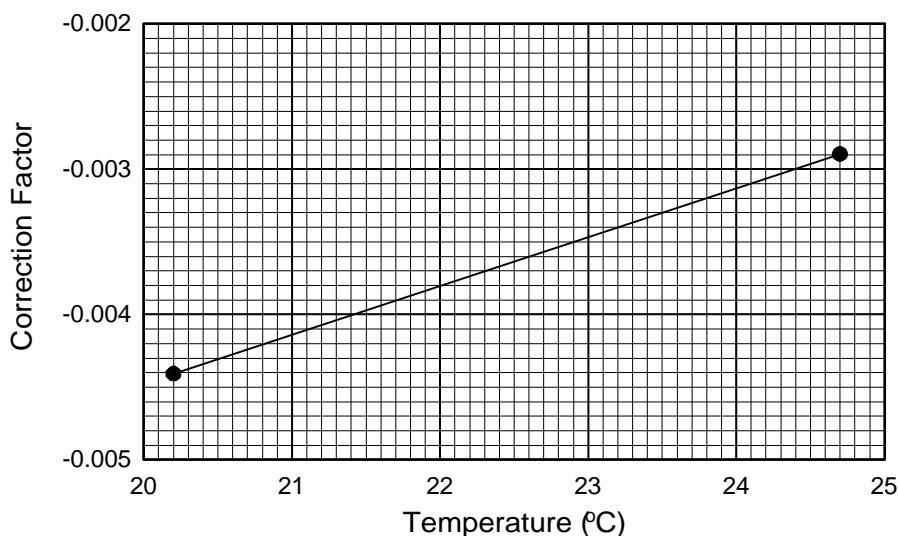
1. Prepare 1000 mL of liquid composed of distilled or demineralized water and dispersing agent in the same proportion as will be used for the test.
2. Place the liquid in a sedimentation cylinder and then place the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used for the test.
3. When the temperature of the liquid becomes constant, insert the hydrometer, wait a short time to allow the hydrometer to come to the temperature of the liquid, then read the hydrometer at the top of the meniscus formed on the stem.
4. For hydrometer 151 H, the composite correction is the difference between this reading and one. For hydrometer 152 H, it is the difference between the reading and zero.

For example, if a hydrometer 151 H is used and the reading is 1.004, the correction factor is 1 minus 1.004 or - 0.004. This correction factor will be added to the readings during the hydrometer test to correct of the errors listed previously.

- Bring the liquid and the hydrometer to the other temperature to be used and calculate the composite correction as before.

Note

For convenience, a graph or table can be prepared for a series of 1-degree temperature differences to be used for future tests. If measurements are made at two known temperatures as outlined, a straight line relationship between the two observed values may be assumed to determine intermediate values for correction.



Hygroscopic Moisture Determination

Hygroscopic moisture is, by definition, the water content of air-dried soil. A sample may also absorb moisture from the air after it has been oven dried. Determination of hygroscopic moisture content allows the mass of the fraction passing the 2.00 mm (No. 10) sieve to be corrected for the presence of moisture. As mentioned earlier, this requires that a representative sample, weighing at least 10 g, be obtained from that fraction passing the 2.00 mm (No. 10) sieve. Determine the hygroscopic moisture as follows:

- Dry the sample and determine the moisture content according to AASHTO T 265, Laboratory Determination of Moisture Content of Soils.

- Calculate the moisture as

$$\% \text{Hygroscopic Moisture} = \frac{W - W_1}{W_1} \times 100$$

percentage of hygroscopic follows:

where: W = mass of air-dried soil
 W_1 = mass of oven-dried soil

The hygroscopic moisture content will be used in later calculations.

Dispersion of Soil Sample

Dispersion of the soil sample should be accomplished as follows:

1. Weigh a sample of approximately 100 g (sandy soil) or 50 g (silty or clayey soil) for hydrometer analysis.
2. Place the sample in a 250 mL beaker.
3. Cover the sample with 125 mL of the stock dispersing agent solution.
4. Stir thoroughly with a glass rod.
5. Allow to soak for a minimum of 12 hours.
6. Wash the contents of the beaker into the dispersion cup.
7. Add distilled or demineralized water until the cup is more than half full.
8. Disperse the contents of the cup for a period of 60 seconds using the mechanical stirring apparatus.

Note

Alternate methods for dispersion using a air-jet dispersion apparatus may also be used. The procedure for using this type apparatus is not covered here, but is described in AASHTO T 88.

Hydrometer Test

After dispersion, the hydrometer test proceeds using the following steps:

1. Transfer the soil mixture to a sedimentation cylinder and wash any residue into the cylinder.
2. Add distilled or demineralized water having the same temperature as the constant temperature bath until the mixture has a volume of 1000 mL.
3. Place the cylinder in the constant temperature bath.
4. Remove the cylinder after the soil mixture has attained the temperature of the bath.
5. Close the open end of the cylinder with a rubber stopper (or place your hand over the open end) and turn the cylinder upside down and back for a period of 60 seconds to completely agitate the soil mixture.

Note

The number of turns during this 60 seconds should be approximately 60, counting the turn upside down and back as 2 turns. Any soil remaining in the bottom of the cylinder after the first few turns should be loosened by vigorously shaking the cylinder while it is upside down.

6. Wash any material that clings to the inside walls of the cylinder and to the stopper (or hand) into the suspended soil mixture using a small amount of water.
7. Return the cylinder to the water bath and record the start time.
8. About 90 seconds after the start time, carefully place the hydrometer in the soil mixture and allow it to come to rest.
9. Exactly 120 seconds after the recorded start time, read the hydrometer at the top of the meniscus formed by the suspension around its stem. If a hydrometer with scale A is used, read to the nearest 0.5 g/L. Read scale B hydrometers to the nearest 0.0005 specific gravity.

Note

The hydrometer must float freely and not touch the wall of the cylinder.

10. Carefully remove the hydrometer from the soil suspension and place it with a spinning motion in a graduated cylinder of clean water.
11. Immediately following the hydrometer reading, measure and record the temperature of the soil suspension by carefully placing the thermometer in the soil suspension.
12. About 25 or 30 seconds before the next reading, remove the hydrometer from the clean water and slowly immerse it again in the soil suspension to assure that it comes to rest before the next reading.
13. Take additional readings at 5, 15, 30, 60, 250 and 1440 minutes after the start time following steps 9 through 12.
14. Correct hydrometer readings by applying the approximate composite correction as determined previously (on Page 11), to account for the dispersing agent, temperature and height of meniscus on the stem of the hydrometer.
15. Calculate the percentage of soil remaining in suspension as follows:

For hydrometer 152 H;

$$P = \frac{Ra}{w} \times 100$$

For hydrometer 151 H;

$$P = \frac{1606(R - 1)a}{w} \times 100$$

where: **P** =

percentage of originally dispersed

soil

remaining in suspension

R = corrected hydrometer reading

w = mass in grams of soil originally dispersed
minus the hygroscopic moisture, and

a = constant depending on the density of the
suspension (from table below)

Specific Gravity, G	Constant, a
2.950	0.94
2.850	0.96
2.750	0.98
2.650	1.00
2.550	1.02
2.450	1.05
2.350	1.08

16. Convert the percentages of soil in suspension to percentages of the total test sample, including the fraction retained on the 2.00 mm (No. 10) sieve by using the following formula.

$$\text{Total Test\%} = P \times \frac{100 - \% \text{Retained on 2.00 mm sieve}}{100}$$

P =
dispersed soil

where:
percentage of originally

remaining in suspension

17. Calculate the maximum diameter of the particles in suspension by using Stokes' Law as in the following formula.

$$d = \sqrt{\frac{30 nL}{980(G - G_1)T}}$$

where: **d** = maximum grain diameter in millimeters

n = coefficient of viscosity of the suspending medium
(in this case water) in Pa•s. Varies with changes
in temperature of the suspending medium

L = distance from the surface of the suspension to the
level at which the density of the suspension is being
measured, mm. (For a given hydrometer and
sedimentation cylinder, values vary according to the
hydrometer readings. This distance is known as the
effective depth (Table 2).)

T = interval of time from beginning of sedimentation to
the taking of the reading, min

G = specific gravity of soil particles, and

G₁ = specific gravity of the suspending medium
(approximately 1.0 for water).

For convenience in calculations, the above equation may be written as:

$$D = K \sqrt{\frac{L}{10 T}}$$

where:

D = maximum grain diameter in millimeters

K = constant from Figure 6, dependent of temperature of suspension and specific gravity of the soil particles

L = distance from the surface of the suspension to the level at which the density of the suspension is being measured, mm.

T = interval of time from beginning of sedimentation to the taking of the reading, min.

10 = SI unit correction factor for particle diameter in mm

Values of K for Use in the Equation for Computing Diameter of Particle in Hydrometer Analysis									
Temperature °C	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01510	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.01323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01225	0.01208	0.01191	0.01175
29	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149

Figure 6 - Values of K for computing Particle Diameter

FINE SIEVE ANALYSIS

After the hydrometer analysis has been conducted determine the percentage of the dispersed soil sample that will be retained on the 0.075 mm (No. 200) sieve.

1. After the final reading of the hydrometer test, pour the suspension through the 0.075 mm (No. 200) sieve.
2. Wash the sample retained on the sieve to remove any material that will pass through the sieve.
3. Dry the retained fraction in an oven at $110 \pm 5^{\circ}\text{C}$ ($230 \pm 9^{\circ}\text{F}$).
4. After the sample has been dried completely, sieve the dried material through the 0.425

mm (No. 40) and 0.075 mm (No. 200) and other sieves that are required for the material being tested.

- Calculate the percentage of the dispersed soil sample retained on each sieve by dividing the mass of the fraction retained on each sieve by the oven-dry mass of the dispersed soil and multiply by 100 as follows.

$$\% \text{Dispersed soil sample retained} = \left(\frac{\text{mass of fraction}}{\text{oven-dry mass}} \right) \times 100$$

- Calculate the percentages of the total test sample, including the fraction retained on the 2.00 mm (No. 10) sieve using the following equation:

$$\% \text{Total test sample} = \frac{100 - \text{percentage retained on the 2.00 mm sieve}}{100}$$

PLOTTING

Plot the accumulated percentages of grains of different diameters on semilogarithmic 27 paper to obtain a "grain size accumulation curve," such as that shown in Figure 7.

REPORT

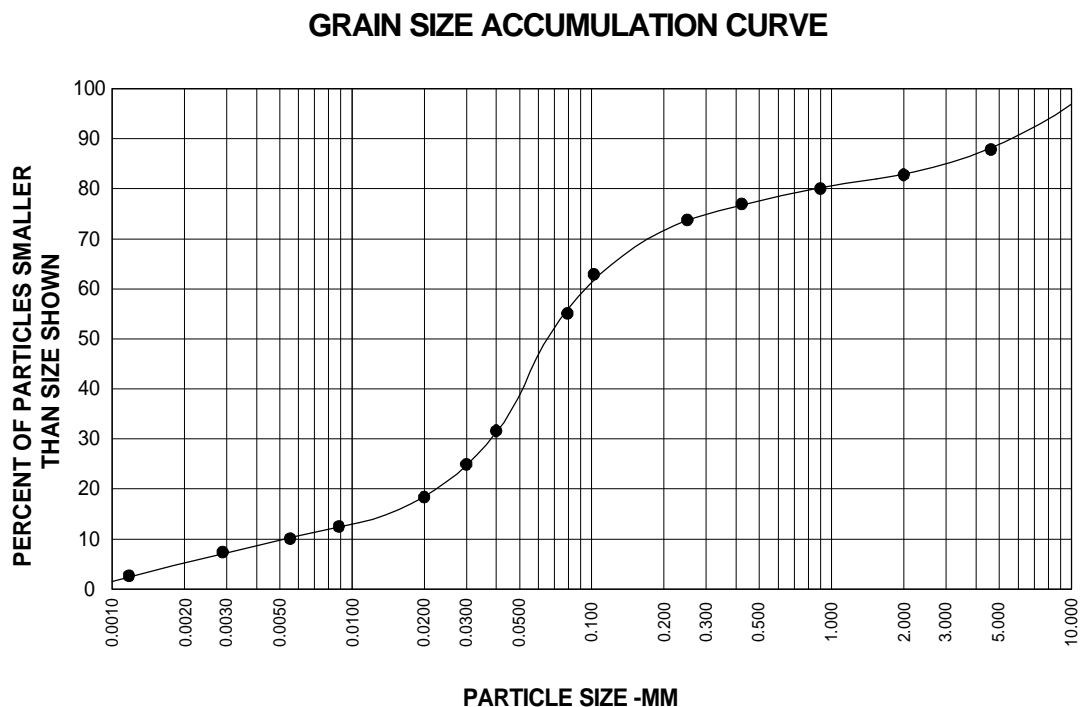


Figure 7 - Grain Size Accumulation Curve

Soil-T88-17

1. Report the results from the accumulation curve as follows (express as a percentage of the total sample):

	<u>Material Type</u>	<u>From Sieve Analysis</u>
(a)	Particles larger than 2 mm	Retained on 2.00mm
(b)	Coarse sand, 2.0 to 0.42 mm	Passing 2.00 mm, retained on 0.425 mm
(c)	Fine sand, 0.42 to 0.074 mm	Passing 0.425 mm, retained on 0.075 mm
(d)	Silt, 0.074 to 0.002 mm	Passing 0.075 mm, larger than 0.002
(e)	Clay, smaller than 0.002 mm	(from hydrometer)
(f)	Colloids, smaller than 0.001 mm	(from hydrometer)

2. Report the results of the combined sieve and hydrometer analysis to the nearest 0.1% as follows:

SIEVE ANALYSIS		
<u>Sieve Size</u>		<u>Percent Passing</u>
<u>Metric</u>	<u>English</u>	
75 mm	3 in.	_____
50 mm	2 in.	_____
25 mm	1 in.	_____
4.75 mm	No. 4	_____
2.00 mm	No. 10	_____
0.425 mm	No. 40	_____
0.075 mm	No. 200	_____

HYDROMETER ANALYSIS	
<u>Smaller Than:</u>	<u>Percent</u>
0.02 mm	_____
0.002 mm	_____
0.001 mm	_____

NOTE

- For materials examined for a particular type of work or purpose, only such fractions that are included in the specifications or other requirements may be necessary.
- Report the Sieve Analysis to the nearest 0.1 percent passing.
- Report the Hydrometer Analysis to the nearest 0.1 percent smaller than.

GLOSSARY

Clay	- An earth material with a particle size smaller than 0.002 mm but larger than 0.001 mm.
Colloids	- Earth material with very small particles, being anything smaller than 0.001 mm.
Hygroscopic Moisture	- Moisture still remaining in soil after it has been air-dried.
Hydrometer	- A floating instrument that is used to determine the specific gravity of a liquid.
Meniscus	- The curved surface of a liquid that occurs where it is in contact with a container wall or other object that breaks the surface of the liquid.
Silt	- An earth material with a particle size smaller than 0.074 mm but larger than 0.002 mm.

DETERMINING THE LIQUID LIMIT OF SOILS

AASHTO T 89



Developed by
FHWA Multi-Regional Soils Training & Certification Group

August 1999

NOTE

Successful completion of the following training materials, including examination and performance evaluation, are prerequisites for this training package.

- ◆ AASHTO T265, Laboratory Determination of Moisture Content of Soils
- ◆ AASHTO T87, Standard Method of Preparing Disturbed Soil Samples

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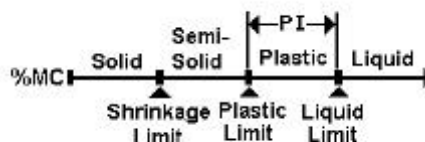
ATTERBERG LIMITS

Soils form the foundation of all transportation facilities. The final structure will be no more durable than the foundation upon which it rests. In order to ensure that the soils which support structures will function as intended in the design, it is necessary for all designers to have basic information about them. Designers use this information to decide if a naturally occurring soil can support the anticipated traffic load or if it will require chemical modification (e.g., cement stabilization, lime treatment or treatment with fly ash) to enable it to perform as a highway foundation. The strength of the soil foundation is also used in determining the type of surface course the designer will choose for a pavement structure.

Several tests are performed in the laboratory that provide information to the designer about soils which may be used as the foundation for a roadway. The determination of Atterberg Limits are among these tests. In 1911, a Swedish scientist, A. Atterberg, developed some simple tests for determining the moisture contents of a soil at which the soil moves from a solid to a semisolid, to a plastic and to a liquid state. The numbers generated by these tests are used to quantitatively describe the effect of varying water contents on a soil. As the moisture content of a soil increases, the soil will eventually change from a solid to a liquid state.

The Atterberg Limits are:

- ◆ Shrinkage Limit - The point at which a soil changes from a solid to a semisolid.
- ◆ Plastic Limit - The point at which a soil moves from a semisolid to a plastic state.
- ◆ Liquid Limit - The point at which a soil moves from a plastic to a liquid state.



Each soil becomes less stable as the moisture increases (moving from left to right on the diagram) after it exceeds the moisture needed for compaction. A soil whose percent moisture content is greater than the Liquid Limit is, therefore, soft and unstable.

Two of these numbers (Liquid Limit and Plastic Limit) are used to determine the Plasticity Index. The Plasticity Index is **not** an Atterberg Limit. It is a number that is derived by subtracting the Plastic Limit of a soil from its Liquid Limit.

$$PI = LL - PL$$

The Plasticity Index of a soil is a measure of the cohesive properties of a soil. It is the numerical range of moisture contents in which a cohesive soil is plastic. Many state highway departments specify Plasticity Index values for soils to be used in construction.

The Shrinkage Limit is not used in determining the Plasticity Index. It is not one of the original Atterberg Limits and is not used as widely in highway construction specifications. The point at which a soil moves from a solid to a semisolid state is not as significant as the Liquid Limit in determining the a soil's suitability for highway construction.

When soil samples are received by the laboratory, they may be identified by a field classification (e.g., plastic, nonplastic, hard, friable, etc.) based on moisture content and consistency at the time of sampling. This field classification provides an indication of a soil's suitability for use in construction. However, a more accurate determination of the soil's behavior at varying moisture contents is needed to ensure that the soils will be able to perform in a pavement structure. Therefore, it is critical that the tests for Atterberg Limits be properly performed. They are one of the criteria used to classify a soil in terms of its suitability for a specific design use and for determining if a soil meets specifications for use in construction projects.

LIQUID LIMIT

The Liquid Limit is the moisture content at which a specific soil moves from a plastic to a liquid state. Generally, soils with high Liquid Limits are clays with poor engineering properties. Soils with a high clay content are cohesive (stick together), plastic (moldable), compressible (able to be consolidated), and nearly impervious (impenetrable by water). Their compressibility leads to rutting under load and can even cause the soil structure to collapse under its own weight, causing embankment failure.

Clay soils become unstable when they react with water. Soils with high clay content also are subject to swelling and shrinking during normal changes in moisture content. The swell/shrinkage cycle will also lead to foundation failure. Swelling and shrinkage are directly related to shear failure. When clay soils are disturbed by construction processes, they lose their shear strength and are, therefore, subject to failure.

Therefore, the Liquid Limit is used to analyze the clay content of a soil. The Liquid Limit is used in conjunction with the Plasticity Index to identify soils with a clay content high enough to keep them from performing well in embankment construction.

SUMMARY OF TESTING

There are two methods approved by AASHTO to determine the Liquid Limit of a soil. The basic test steps are the same for both methods. The differences are in the initial quantity of water added to the test specimen; the number of specimens which are tested; the mandatory blow count range; and the calculations involved. When the results of Method B or the use of tap water cause questionable test results, there is also a reference method that must be used to establish the validity of the values. This reference method uses Method A with special parameters to ensure exacting testing standards.

The Liquid Limit test is performed on material passing the 0.425 mm (No. 40) sieve. First mix the test specimen with water, alternately stirring and chopping the soil and adding water until the soil is at a uniform stiff consistency. You will need some experience to recognize when you have reached the correct consistency for each soil type. Place some of the test specimen in the cup of the Liquid Limit device. Then use the spatula to press and spread the material to the correct thickness. Be careful not to trap air bubbles in the test specimen when spreading it in the cup.

Use the grooving tool to divide the test specimen in the cup through its center moving the tool from back to front only one time for each stroke. Be sure to form a clean, sharp groove. Use no more than six strokes of the grooving tool to divide the specimen; only the last stroke of the grooving tool is to scrape the bottom of the cup.

If you are using a manual device, turn the crank at approximately 2 revolutions per second. If you are using an automatic device, turn on the machine. Count the number of blows of the machine or use the automatic counter if the device is equipped with one. When the groove closes to 13 mm (0.5 inch), stop the device. Record the number of blows the device needed to close the groove.

For Method A, repeat these steps at least three times until you have blow counts within the following ranges:

➤ 25 - 35 ➤ 20 - 30 ➤ 15 - 25

There must be a difference of at least ten blows between the high and low blow count for the test result to be valid.

For Method B, the blow count must be within the range of 22-28, inclusive, and only one specimen is used for testing. A second specimen is run to verify the blow count.

From each test specimen, remove a slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right angles to the groove. Be sure to take that portion of the groove in which the soil flowed together. Then, determine the moisture content of each specimen in accordance with AASHTO T265. The Liquid Limit is a mathematical calculation based on the moisture content and number of blows at closure.

TYPICAL TEST RESULTS

Liquid Limits vary widely. It is possible to obtain values as high as 80 - 100. Values between 40 - 60 are typical of clay soils. For silty soils, typical values are between 25 - 50. The Liquid Limit test will not produce a result for sandy soils; sandy soils are termed nonplastic.

COMMON TESTING ERRORS

- ▶ Improperly adjusted Liquid Limit device.
- ▶ Loose adjusting screws.
- ▶ Excessively worn pin.
- ▶ Excessively worn base or cup.
- ▶ Worn grooving tool.
- ▶ Automatic counter not zeroed.
- ▶ Miscounting blows on manual device.
- ▶ Restraining the base of the Liquid Limit device during testing.
- ▶ Trapping air bubbles in the test specimen.
- ▶ Soil cake of improper thickness.
- ▶ Moisture content test specimen not representative of Liquid Limit test specimen.
- ▶ Plotting or calculation errors.
- ▶ Nonuniform moisture content in sample.
- ▶ Performing test before moisture content in soil specimen is equalized.
- ▶ Contaminated water used for testing.
- ▶ Adding water too quickly for the soil to absorb it during the mixing process

TEST METHODOLOGY - METHOD A

Before beginning any procedure, you must first assemble all the equipment you will need to perform the test. To determine the Liquid Limit of a soil specimen, you will need the following.

- ◆ Dish - An unglazed porcelain dish (or similar mixing dish), approximately 115 mm (4 ½ inches) in diameter
- ◆ Cover - A cover to be used over the dish to prevent moisture loss during testing
- ◆ Spatula - A spatula or pill knife with a blade approximately 75 - 100 mm (3 - 4 inches) long and approximately 20 mm (¾-inch) wide
- ◆ Liquid Limit Device - Manual or mechanically operated conforming to AASHTO T89
- ◆ Grooving Tool - Conforming to AASHTO T89, Figure 1
- ◆ Gage - Conforming to AASHTO T89, Figure 1 or a metal bar 10.0 ±0.2 mm (0.394 ±0.008 inches) thick and approximately 50 mm (2 inches) long
- ◆ Containers - Enough containers with close-fitting lids to provide one container for each moisture content determination. Containers must be resistant to corrosion and not subject to change in mass with repeated heating and cooling.
- ◆ Balance - Conforming to AASHTO M231, Class C
- ◆ Oven - A thermostatically controlled oven capable of maintaining a temperature of 110 ±5°C (230 ±9°F)
- ◆ Distilled or Demineralized Water or Tap Water, if approved
- ◆ Semi-logarithmic Graph Paper
- ◆ AASHTO T265 (For the Determination of Moisture Content)
- ◆ Stable, flat surface - Support for testing apparatus to ensure uniform impact and base stability of device



Testing Apparatus

Test Specimen

Prepare a soil sample in accordance with AASHTO T87, Standard Method of Preparing Disturbed Soil Samples, or in accordance with AASHTO T146, Standard Method of Wet Preparation of Disturbed Soil Samples. Separate the material passing the 0.425-mm (No. 40) sieve. Obtain a representative portion of approximately 100 grams from this material.



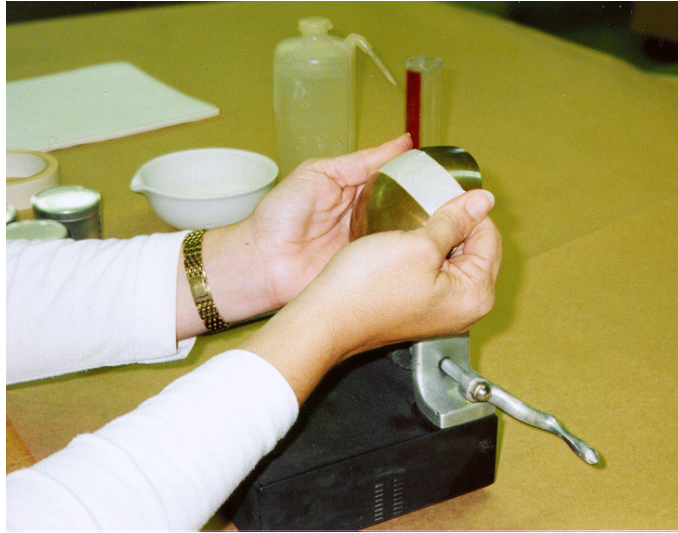
Weighing Test Specimen

Procedure Preparation

1. Inspect the Liquid Limit device and grooving tool.
 - A. Check that the pin connecting the cup is not worn to the point of allowing side play.
 - B. Check that the screws connecting the cup to the hanger arm are tight. Loose screws allow excessive cup movement and cause erratic blow counts.
 - C. Check that the points of contact on the cup and base are not excessively worn. Excessive wear is defined as approximately 13 mm (0.5 inches) in diameter. Check the lip of the cup for excessive wear. Excessive wear is defined as when any point on the cup rim is worn to approximately $\frac{1}{2}$ the original thickness.
 - D. Check the center of the cup to ensure that use has not worn a groove into the cup. (Replace any cup in which there is a pronounced groove.)
 - E. Check the cam follower. It should not be worn beyond the tolerance allowed or allow any rocking on the height gage when checking height of drop.
 - F. Check the adjusting screws. All screws in the adjusting assembly must be tight with no noticeable movement.
 - G. Check the dimensions of the grooving tool to ensure that the tool continues to conform to the tolerances of AASHTO T89, Figure 1.
2. Adjust the height of drop so that the point on the cup that contacts the base rises to a height of 10.0 ± 0.2 mm (0.394 ± 0.008 in.)
 - A. Mark the point of contact of the cup with the base. Facing the front of the cup, raise the cup by hand. Place a piece of masking tape across the outside bottom of the cup. Place the tape parallel to the pivot pin with the top edge of the tape bisecting the wear mark on the cup where it contacts the base.

NOTE

When a cup is new, place a piece of carbon paper on the base, carbon side up, then allow the cup to drop several times to mark the contact spot.



Placing Masking Tape on Cup Bottom

- B.** Lower cup into position.

NOTE

You may remove the cup from the device to apply the tape. If this was done, place cup on device and install pivot pin.

- C.** Turn the crank and raise the cup to its maximum height.
- D.** Slide the height gage under the cup from the front until the gage contacts the edge of the tape on the cup. If the gage contacts the cup at the edge of the tape, the adjustment is approximately correct.



Checking Contacts with Height Gage

- E.** If the gage does not contact the cup at the edge of the tape, use the adjusting screw device to adjust the height until the cup is in proper position. Lock the adjustment assembly into proper position.
- F.** Leave the gage in position. Check the adjustment by turning the handle at two revolutions per second. If the cup does not move and a ringing or clicking sound is heard, the adjustment is correct. If no sound is heard or if the cup rises from the gage, re-adjust the height of drop.
- G.** Remove the tape as soon as the check procedure is completed.

Testing Procedure

I. Prepare Test Specimen

- A. Place the test specimen in the mixing dish. Add 15 - 20 mL of water. Mix thoroughly by alternately stirring, kneading, and chopping with the spatula. Add enough water to form a soil mass with a stiff consistency. After the initial addition of 15 - 20 mL of water, add subsequent water in increments of 1 - 3 mL. Mix each increment of water thoroughly into the soil mass before adding the next increment.

NOTE

It is permissible to use tap water for routine testing, if comparative tests indicate no difference in test results.



Adding Water



Blending Water and Soil

- B. If too much water is added, either discard the test specimen or continue mixing and kneading the material until natural evaporation lowers the moisture content to the proper consistency.
- C. Do not add additional dry material to the test specimen.

NOTE

Do not use the cup of the Liquid Limit device to mix the soil and water.

NOTE

Some soils (fine silts and clays) are slow to absorb water.

When testing such soils, allow additional mixing time to ensure water absorption. If water is added too quickly to these soils, it is possible to obtain a false value for the liquid limit.

II. Perform Test

- A. Use the spatula to scoop a representative specimen of the mixed material about the size of a golf ball. Immediately cover mixing dish to eliminate moisture loss.
- B. Place this specimen in the cup of the liquid limit device directly above the point where the cup rests on the base.
- C. Use the spatula to press, spread, and level the specimen so that the material is no more than 10 mm thick at its maximum thickness and is centered as close as possible over the contact point of the cup and the base. Use as few spatula strokes as possible. Do not trap air bubbles within the mass.



Spreading Specimen in Liquid Limit Cup

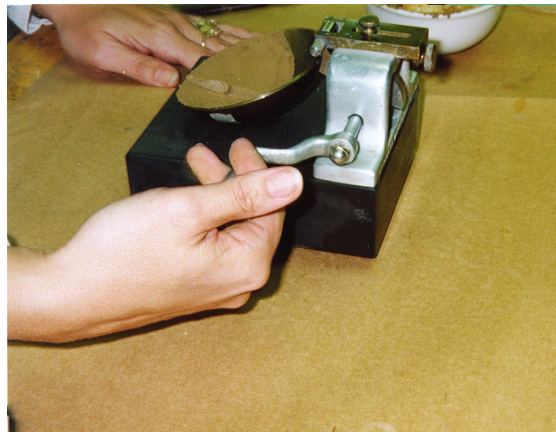
- D. Trim excess soil from the specimen during Step C, return the excess to the mixing dish and immediately cover to prevent moisture loss.

- E.** Use the grooving tool to make a smooth firm stroke through the soil pat. Move the grooving tool from back to front through the center of the soil pat. Do not allow the soil pat to tear or slide in the cup while making the groove. (If the soil pat tears or slides, the soil is too dry or may be nonplastic. You will have to add more water and try again.) Increase the depth of the groove with each stroke, but do not allow the tool to touch the bottom of the cup, except on the last stroke. Use no more than six strokes to complete the division. While grooving the material, you can use the curved end of the grooving tool to determine if the pat is the proper thickness. When the grooving tool touches the cup, the top of the soil cake should be level with the top of the curved portion of the grooving tool. The curved portion of the grooving tool is 10 mm (0.4 inch) high.



Grooving the Soil Specimen

- F.** Apply blows. If the device is automatic, turn on the device. If the device is manual, turn the crank at approximately two revolutions per second. Continue applying blows until the two sides of the material come in contact at the bottom of the groove along a distance of about 13 mm (0.5 in.).



Applying Blows by Turning the Handle

NOTE

Do not hold the base of the device with the free hand while turning the crank.

NOTE

Some soils tend to slide on the surface of the cup instead of flowing together. If this occurs, remix the material with additional water and repeat the procedure. If the soil continues to slide at fewer than 25 blows, the Liquid Limit test is not applicable. Record that the Liquid Limit could not be determined.

- G.** Record the number of blows needed to close the groove to 13 mm (0.5 in.)

III. Determine Moisture Content

- A. Use the spatula to take a slice of soil from the specimen in the cup. Remove the slice from edge to edge of the soil cake at right angles to the groove. Include that portion of the groove where the soil has flowed together. Place the slice in a drying container.



Removing the Moisture Content Specimen



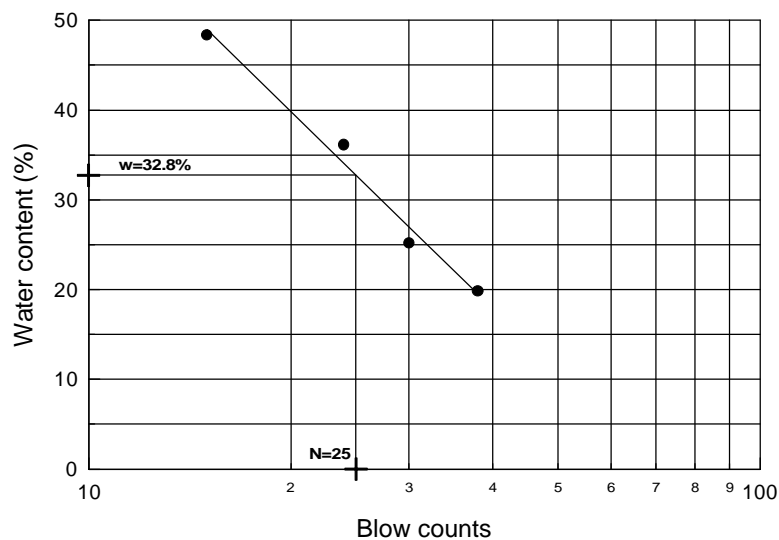
Placing Specimen in Drying Container

- B. Determine the moisture content of the slice in accordance with AASHTO T 265.
- C. Put the remaining part of the soil cake back into the mixing dish and cover it.
- D. Wash and dry the cup and grooving tool.
- E. Add more water to the material in the mixing dish and remix, making the material more fluid. The intent is to increase the fluidity of the soil by 5 shocks (blows).
- F. Repeat Steps II.A. - II. F. at least twice, until at least one determination is made in each of the following ranges. The range of the three determinations must be at least 10 blows.
- 25 - 35 ➤ 20 - 30 ➤ 15 - 25
- G. Determine the percentage of moisture to the nearest 0.1% for each test specimen in accordance with AASHTO T 265.

IV. Flow Curve Preparation

- A. Prepare semi-logarithmic graph paper by labeling the x and y axes for moisture content and number of shocks.
- B. For each test specimen, plot the point corresponding to the blow count and moisture content.
- C. Draw a flow curve (as straight a line as possible passing through all plotted points).

Example



NOTE

The lower point, although recorded, was outside the 25 - 35 range. The course developers, unlike AASHTO directions, prefer that all points be recorded.

V. Determine the Liquid Limit

Identify the moisture content at which the flow curve intersects the 25-blow line. The moisture

content at the intersection of the flow curve and the 25-blow line is the Liquid Limit. Record the Liquid Limit to the nearest whole number.

REFERENCE TESTS

When performing Method A as a reference test, use the following time schedule.

1. Mixing of soil with water: **5 - 10 minutes**
The more plastic the soil, the longer the mixing time should be.
2. Seasoning in the humidifier: **30 minutes**
3. Remixing the material before placing it in the brass cup:
Add 1 mL of water and mix: **1 minute**
4. Placing the material in the brass cup: **3 minutes, maximum**
5. Adding water and remixing: **3 minutes**
6. Do not add dried soil to the seasoned soil during the test.

TEST METHODOLOGY - METHOD B

Method B is a quicker determination of Liquid Limit, because it is only necessary to run one complete point. If results from Method B are questionable, use Method A as a referee test with the special parameters listed under reference test.

You will need the same equipment as for Method A, except you will not need semi-logarithmic graph paper. In addition to the equipment listed for Method A, you will need one of the following:

- ◆ Liquid Limit Slide Rule
- ◆ Calculator
- ◆ Liquid Limit Nomograph
- ◆ Other Approved Charts or Graphs

NOTE

The discussion in this training package for Method B will be limited to the Corps of Engineers Nomograph and the determination of Liquid Limit by formula.

Test Specimen

Obtain a test specimen of approximately 50 g in accordance with the directions in Method A.

Procedure

1. Prepare the test specimen and perform the test exactly like Method A, with the following exception.
 - A. Use approximately 8 - 10 mL of water for initial specimen preparation.
 - B. The blow count must be between 22 - 28, inclusive.
 - C. After the blow count is in the correct range, return the material from the cup to the mixing dish. Remix quickly, being sure to avoid moisture loss during remixing. Repeat the blow count procedure without adding additional water to reaffirm the blow count.
2. When blow count is acceptable, obtain the slice of soil from the specimen in the cup and

determine moisture content in accordance with AASHTO T 265.

Determine Liquid Limit

Use one of the methods shown in AASHTO T 89 to determine the Liquid Limit. In this training package only the formula and nomograph are shown as examples.

1. Use the following formula to determine the Liquid Limit.

$$LL = W_N \left(\frac{N}{25} \right)^{0.121}$$

Where: LL = Liquid Limit
N = Blow Count
 W_N = Moisture Content at Blow Count, %
25 = Constant, Midrange of Acceptable Blow Count
0.121 = Empirical Constant

Example

$$\begin{aligned} N &= 23 \\ W_N &= 48.5 \end{aligned}$$

$$LL = W_N \left(\frac{N}{25} \right)^{0.121}$$

$$LL = 48.5 \left(\frac{23}{25} \right)^{0.121}$$

$$LL = 48.5(0.99)$$

$$LL = 48.01 = 48$$

2. Use the Nomograph to determine the Liquid Limit.

(Refer to the Nomograph in AASHTO T 89.)

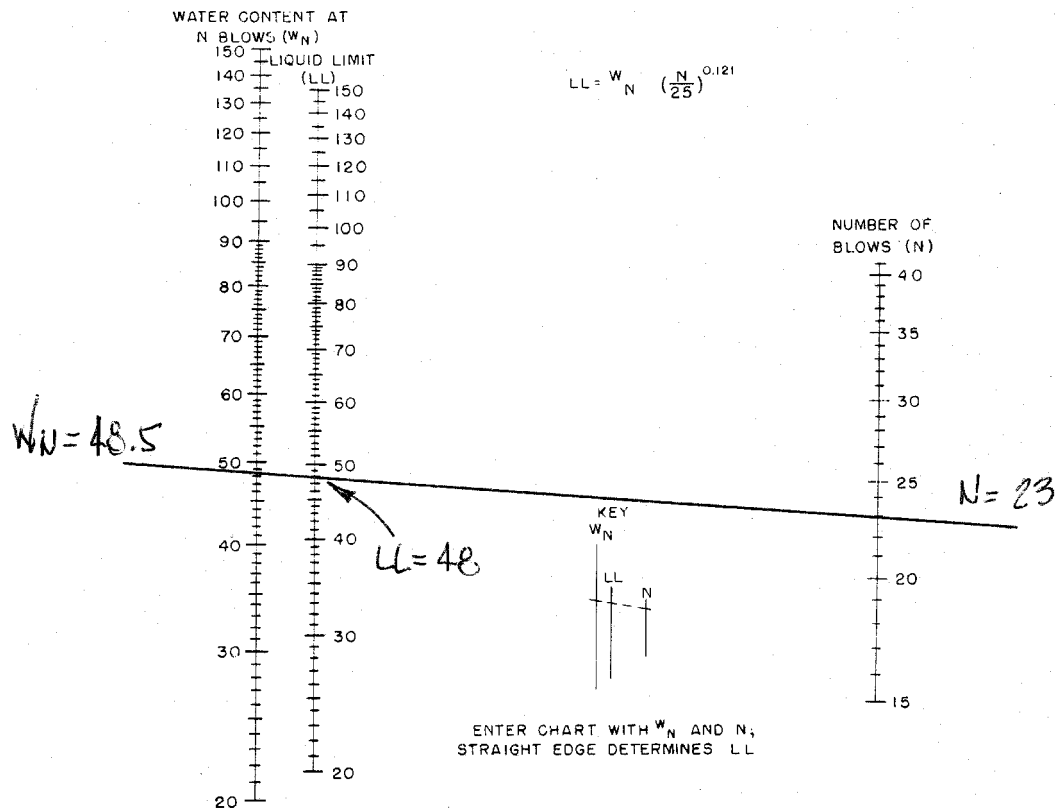
(1) Plot the moisture content (W_N) on the left vertical column.

(2) Plot the blow count (N) on the right vertical column.

(3) Using a straightedge, connect the two points.

(4) Read the Liquid Limit from the middle column.

Example: $W_N = 48.5$
 $N = 23$



Developed by the Waterways Experiment Station, Corps of Engineers
U. S. Army, to determine Liquid Limit Using Mean Slope Method
Excerpted From AASHTO T89

GLOSSARY

- Atterberg Limits** - Tests designed by A. Atterberg. Used to identify the limits at which a soil passes from a solid, semisolid, plastic, and liquid states. Atterberg Limits are the Plastic Limit, Liquid Limit and Shrinkage Limit. The Plastic Limit and Liquid Limit are used to determine the Plasticity Index.
- Cohesive** - Tending to stick together
- Compressibility** - Able to be reduced in volume through compaction.
- Friable** - A noncohesive material which crumbles readily.
- Liquid Limit** - An Atterberg Limit. The moisture content at which a soil moves from a plastic to a liquid state.
- Plastic** - Capable of being molded into a sustainable shape.
- Plastic Limit** - An Atterberg Limit. The moisture content at which a soil moves from a semisolid to a plastic state.
- Plasticity Index** - A measure of the cohesive properties of a soil. Determined by subtracting the Plastic Limit from the Liquid Limit.
- Nonplastic** - Not capable of being molded into a sustainable shape.
- Shrinkage Limit** - An Atterberg Limit. The moisture content at which a soil changes from a solid to a semisolid.
- Shear** - Failure in a soil parallel to the direction of applied force.

DETERMINING THE PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

AASHTO T 90



Developed by
FHWA Multiregional Soils Training & Certification Group

August 1999

NOTE

Successful completion of the following training materials, including examination and performance evaluation, are prerequisites for this training package.

- ◆ AASHTO T 265, Laboratory Determination of Moisture Content of Soils
- ◆ AASHTO T 87, Standard Method of Preparing Disturbed Soil Samples
- ◆ AASHTO T 89, Determining the Liquid Limits of soils

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Typical Test Results	Soils - T 90 - 4
Common Testing Errors	Soils - T 90 - 4
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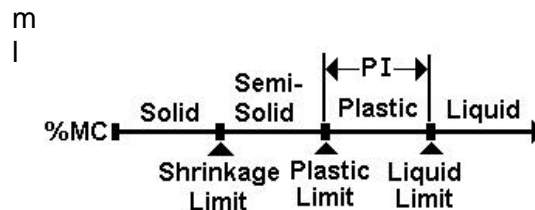
ATTERBERG LIMITS

Soils form the foundation of all transportation facilities. The final structure will be no more durable than the foundation upon which it rests. In order to ensure that the soils which support structures will function as intended in the design, it is necessary for designers to have basic information about them. Designers use this information to decide if a naturally occurring soil can support the anticipated traffic load or if it will require chemical modification (e.g., cement stabilization, lime treatment or treatment with fly ash) to enable it to perform as a highway foundation. The strength of the soil foundation is also used in determining the type of surface course the designer will choose for a pavement structure.

Several tests are performed in the laboratory that provide information to the designer about soils which may be used as the foundation for a roadway. The determination of Atterberg Limits are among these tests. In 1911, a Swedish scientist, A. Atterberg, developed some simple tests for determining the moisture contents of a soil at which the soil moves from a solid to a semisolid, to a plastic and to a liquid state. The numbers generated by these tests are used to quantitatively describe the effect of varying water contents on a soil. As the moisture content of a soil increases, the soil will eventually change from a solid to a liquid state.

Atterberg Limits are the:

- ◆ Shrinkage Limit - The point at which a soil changes from a solid to a semisolid.
- ◆ Plastic Limit - The point at which a soil moves from a semisolid to a plastic state.
- ◆ Liquid Limit - The point at which a soil moves from a plastic to a liquid state.



Each soil becomes less stable as the moisture increases (moving left to right on the diagram) after it exceeds the moisture needed for compaction. A soil whose percent moisture content is greater than the Liquid Limit is, therefore, soft and unstable.

Two of these numbers (Liquid Limit and Plastic Limit) are used to determine the Plasticity Index. The Plasticity Index is **not** an Atterberg Limit. It is a number that is derived by subtracting the Plastic Limit of a soil from its Liquid Limit.

$$PI = LL - PL$$

The Plasticity Index of a soil is a measure of the cohesive properties of a soil. It represents the range of moisture contents in which a cohesive soil is plastic. Many state highway departments specify Plasticity Index values for soils to be used in construction.

The Shrinkage Limit is not used in determining the Plasticity Index. It is not one of the original Atterberg Limits and is not used as widely in highway construction specifications. The point at which a soil moves from a solid to a semisolid state is not as significant as the Liquid Limit in determining the shear strength and compressibility of a soil.

When soil samples are received by the laboratory, they may have a field classification (e.g., plastic, nonplastic, hard, friable, etc.) based on their moisture content and consistency at the time of sampling. This field classification provides an indication of a soil's suitability for use in construction. However, a more accurate determination of the soil's behavior at varying moisture contents is needed to ensure that the soils will be able to perform in a pavement structure. Therefore, it is critical that the tests for Atterberg Limits be properly performed. They are one of the criteria used to classify a soil in terms of its suitability for a specific design use and for determining if a soil meets specifications for use in construction projects.

PLASTIC LIMIT

As the moisture content of a soil moves below the Liquid Limit, it becomes more plastic. External force is needed to make the soil deform. Its bearing capacity begins to increase. The soil becomes more cohesive and can be molded by hand into a ball or other shape. The minimum moisture content at which a soil begins to behave as a plastic is called the Plastic Limit. The Plastic Limit is determined by a simple test in which the soil is repeatedly rolled into threads approximately 3 mm in diameter. During the repeated rollings, the soil gradually loses moisture until it reaches the point where it will no longer hold together and breaks into short pieces. The moisture content at the point where the soil begins to break up is the Plastic Limit.

PLASTICITY INDEX

The range of moisture contents at which a soil is considered to be plastic are those which fall between the Liquid Limit and the Plastic Limit. This range is identified as an engineering property by the Plasticity Index (PI). The Plasticity Index is a calculated value derived by subtracting the Plastic Limit from the Liquid Limit.

$$PI = LL - PL$$

The Plasticity Index is an indicator of the suitability of the clay fraction of a soil or soil-aggregate for use in highway construction. It is used as a specification by many highway departments to determine the usability of a soil. When the Plasticity Index of the binder fraction of a material containing clay is too high, the material will tend to soften under wet conditions. Pavements constructed with soils or soil-aggregates having a high PI tend to have problems with rutting, shifting and shoving. They may develop a washboard surface or other failures that are caused by foundation failures. When such materials are used as surfacings,

they tend to become slippery in wet weather. When the Plasticity Index is too low or the soil fraction is nonplastic, the material will tend to become friable in dry weather. It may ravel at the edges and abrade under traffic. Pavement surfacings constructed with low PI material tend to be dusty and may lose much of their binder during dry periods. The Plasticity Index is one of the factors considered in determining the classification of soils.

Since the Plasticity Index is the numerical range of moisture contents through which a soil remains plastic, each soil becomes less stable as the moisture content increases (moves left to right on the graph) after it exceeds the moisture content needed for proper compaction. A soil the natural moisture content of which exceeds the Liquid Limit is, therefore, soft and unstable.

It is possible for a soil to have a PI of zero, if the Plastic Limit and Liquid Limit are the same. Such a soil is considered plastic, although the range of moisture contents at which the material behaves as a plastic is so severely limited that the range cannot be determined by standard laboratory tests. Soils with a PI of zero should not be confused with nonplastic soils. Nonplastic soils (generally sands) are almost totally free of clay particles. Nonplastic soils never reach a cohesive state, but move abruptly from a viscous liquid state to a dry granular state. A nonplastic soil will not solidify. It will not form clods or other solid masses. It cannot be rolled into a thread as small as 3.2 mm (1/8 inch) and, therefore, cannot be tested for a Plastic Limit.

SUMMARY OF TESTING

To determine the Plastic Limit of a soil, you will first add water to a dried soil sample and mix it thoroughly. When the moisture content is uniform, place the test specimen on a flat, smooth, impermeable surface and, with the heel of the hand, roll it into a thin thread. Remold the test specimen, without adding additional water. Repeat the procedure until the specimen crumbles. Then, you determine the moisture content of the test specimen in accordance with AASHTO T 265. The moisture content is the Plastic Limit. You can then determine the Plasticity Index by subtracting the Plastic Limit from the Liquid Limit, determined in accordance with AASHTO T 89.

TYPICAL TEST RESULTS

Plastic Limit tests are conducted on silts and clays. Normally, silty soils have lower Plastic Limits than clay soils. The Plastic Limit usually falls in the range of 5 - 30. Nonplastic materials (e.g., sand) cannot be tested by this procedure. Nonplastic materials lack the cohesiveness to be rolled into a thread.

The Plasticity Index can range as high as 70 or 80 for very plastic clays. However, most clays have a PI of 20 - 40 and silts have a PI of 10 - 20.

COMMON TESTING ERRORS

- ▶ Nonuniform mixing of soil and water
- ▶ Contaminated water
- ▶ Improperly blended sample
- ▶ Too thin or too thick soil threads
- ▶ Errors in determining mass
- ▶ Applying too much pressure or nonuniform pressure in rolling
- ▶ Rolling on the wrong type surface

CRUMBLING

Different types of soils exhibit different styles of breaking up during rolling. Some soils fall apart in many small aggregations; others form a tubular layer on the outside that splits at both ends. When this occurs, the splitting tends to progress toward the middle until the thread falls apart in many small platy particles. Heavy clays require a lot of pressure to deform the soil, especially as it approaches the Plastic Limit. With clay soils, the thread often breaks into a series of barrel-shaped segments about 6.4 - 9.5 mm (1/4 - 3/8 inch) in length.

The technician is never to attempt to produce failure at exactly 3.2 mm (1/8 inch) by reducing the rate of rolling or modifying hand pressure. It is acceptable to reduce the amount of rolling required for soils with low plasticity by making the initial diameter of the ellipsoidal test specimen near the 3.2 mm (1/8 inch) final diameter.

TEST METHODOLOGY

Before beginning any procedure, you must first assemble all the equipment you will need to perform the test. To determine the Plastic Limit of a soil specimen, you will need the following.

- ◆ Dish - An unglazed porcelain dish (or similar mixing dish), approximately 115 mm (4 ½ inches) in diameter
- ◆ Spatula - A spatula or pill knife with a blade approximately 75 - 100 mm (3 - 4 inches) long and approximately 20 mm (3/4-inch) wide
- ◆ Surface for Rolling - Glass Plate or Smooth, Unglazed Paper
- ◆ Containers - Enough containers with close-fitting lids to provide one container for each moisture content determination. Containers must be resistant to corrosion and not subject to change in mass with repeated heating and cooling.
- ◆ Balance - Conforming to AASHTO M231, Class C
- ◆ Oven - A thermostatically controlled oven capable of maintaining a temperature of $110 \pm 5^{\circ}\text{C}$ ($230 \pm 9^{\circ}\text{F}$)



Figure 1: Equipment for Plastic Limit

Test Specimen

Prepare a soil sample in accordance with AASHTO T 87, Standard Method of Preparing Disturbed Soil Samples. Separate the material passing the 0.425-mm (No. 40) sieve. Obtain a representative portion of approximately 20 grams from this material if you are only going to perform the test to determine the Plastic Limit.

Place the air dried soil in a mixing dish and thoroughly mix with water until it can be easily shaped into a ball. Knead the material into plastic mass until the moisture content and texture are uniform. Take a ball of approximately 8 g to perform the test.



Figure 2: Test Specimen for Plastic Limit

PROCEDURE

- I. Squeeze the 8 g test specimen into an ellipsoidal mass.
- II. Place the test specimen on the rolling surface. Applying just enough pressure to cause the specimen to move, roll it back and forth with your hand until it forms a thread of uniform diameter throughout its length. Roll it back and forth at a speed of approximately 80 - 90 strokes per minute being sure to apply pressure uniformly during the procedure. A stroke equals one complete motion back and forward to the starting point.



Figure 3: Rolling the Test Specimen



Figure 4: Continuing to Roll the Test Specimen

- III. When the diameter of the thread becomes 3.2 mm (1/8 inch), stop rolling. Break the thread into six or eight reasonably equal-sized pieces.

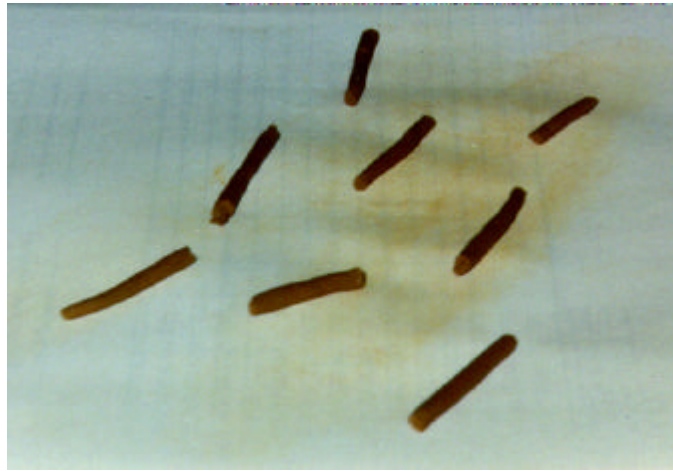


Figure 5: Individual Pieces

- IV. Squeeze the pieces between the thumbs and fingers to create a uniform ellipsoidal mass.
- V. Repeat Steps II - IV, until the thread crumbles under the pressure required for rolling and the specimen can no longer be rolled into a thread.

NOTE

The test specimen may crumble when the thread has a diameter greater than 3.2 mm (1/8 inch). It is acceptable to end the rolling procedure at this point if the specimen has previously been rolled to the 3.2 mm-diameter.

- VI. Gather the pieces of the crumbled thread together. Place them in a tared container that is suitable for drying to determine the moisture content.
- VII. Determine the moisture content in accordance with AASHTO T 265 and record the results.

CALCULATIONS

- I. Determine the Plastic Limit using the following formula and report the result to the nearest whole number.

$$PL = \frac{\text{Mass of Water}}{\text{Mass of Oven - Dry Soil}} \times 100$$

Example

$$\begin{array}{lcl} \text{Mass of Water} & = & 5.3 \text{ g} \\ \text{Mass of Oven} & & \\ \text{Dry Soil} & = & 22.0 \text{ g} \end{array}$$

$$PL = \frac{5.3}{22.0} \times 100$$

$$PL = 0.2409 \times 100$$

$$PL = 24.09 = 24$$

- II. Determine the Plasticity Index using the following formula and report the result to the nearest whole number.

$$PI = LL - PL$$

$$\begin{array}{lcl} \text{Example} & LL = & 70 \\ & PL = & 24 \end{array}$$

$$PI = 70 - 24$$

$$PI = 46$$

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MOISTURE-DENSITY RELATIONS OF SOILS

Standard Method
AASHTO T 99

Modified Method
AASHTO T 180



Developed by
FHWA Multi-Regional Soils and Certification Group

NOTE

Successful completion of the following training manuals, including examination and performance evaluation are prerequisites for this training package

- ▶ ASTM D 3365, Standard Practice for Random Sampling of Consturction Materials
- ▶ ASTM D 2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)
- ▶ AASHTO T 87, Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Test
- ▶ AASHTO T 88, Particle Size Analysis of Soils
- ▶ AASHTO T 265, Laboratory Determination of Moisture Content of Soils

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MOISTURE - DENSITY RELATIONS OF SOILS

Standard Method (AASHTO T 99)

Modified Method (AASHTO T 180)

Soils form the foundation for most highway structures. The final structure, whether it is a pavement or a bridge structure, can only be as durable as the foundation upon which it rests. Compaction of the soil is necessary in order to assure that the soil or soil aggregate structure will perform and support its intended design loads. Material that is densely compacted will support more load than uncompacted material.

The principles of compaction were developed by R. R. Proctor in the 1930's. Proctor noted that compaction is a function of four variables:

- ! **Compaction Effort**
- ! **Soil Type**
- ! **Dry Density, and**
- ! **Moisture Content**

The "percent compaction" is a comparison between the compaction actually achieved in the field (in place density) and the maximum compaction possible for that soil type when compaction is performed under a set of controlled conditions. These controlled conditions exist in the laboratory. AASHTO T 99 and T 180 are used to determine the maximum possible density that can be expected for that specific soil type using normal construction compacting efforts. Maximum density of a soil or soil-aggregate is also dependent on the optimum moisture content of the soil being tested. Since it is possible that several types of soil will be used on a particular construction project, it is necessary for a laboratory to test and develop the different moisture-density relationships for each soil or soil aggregate that will be encountered.

A soil or soil aggregate mixture which is not compacted to the required density may subside or collapse due to its own mass or traffic loadings, causing failure of the highway structure. It is critical that these tests and procedures which determine the maximum density and the optimum moisture content be performed properly.

SUMMARY OF PROCEDURE

This procedure determines the moisture-density relationship of soils and soil-aggregate mixtures. It is sometimes referred to as the standard proctor or the modified proctor test. A quantity of soil or soil and aggregate mixture is prepared at a determinable moisture content and compacted in a standard mold using a manual or mechanical rammer. The wet mass of this compacted sample is divided by the volume of the mold to determine the wet density. Moisture content testing on the material from the compacted mass is used to determine the dry density of this material. This procedure is repeated at varied moisture contents and the results are plotted on a graph as shown in Figure 1. A smooth line is drawn through the points to obtain a curve. The maximum density and optimum moisture content are determined by selecting a point at the peak of the curve.

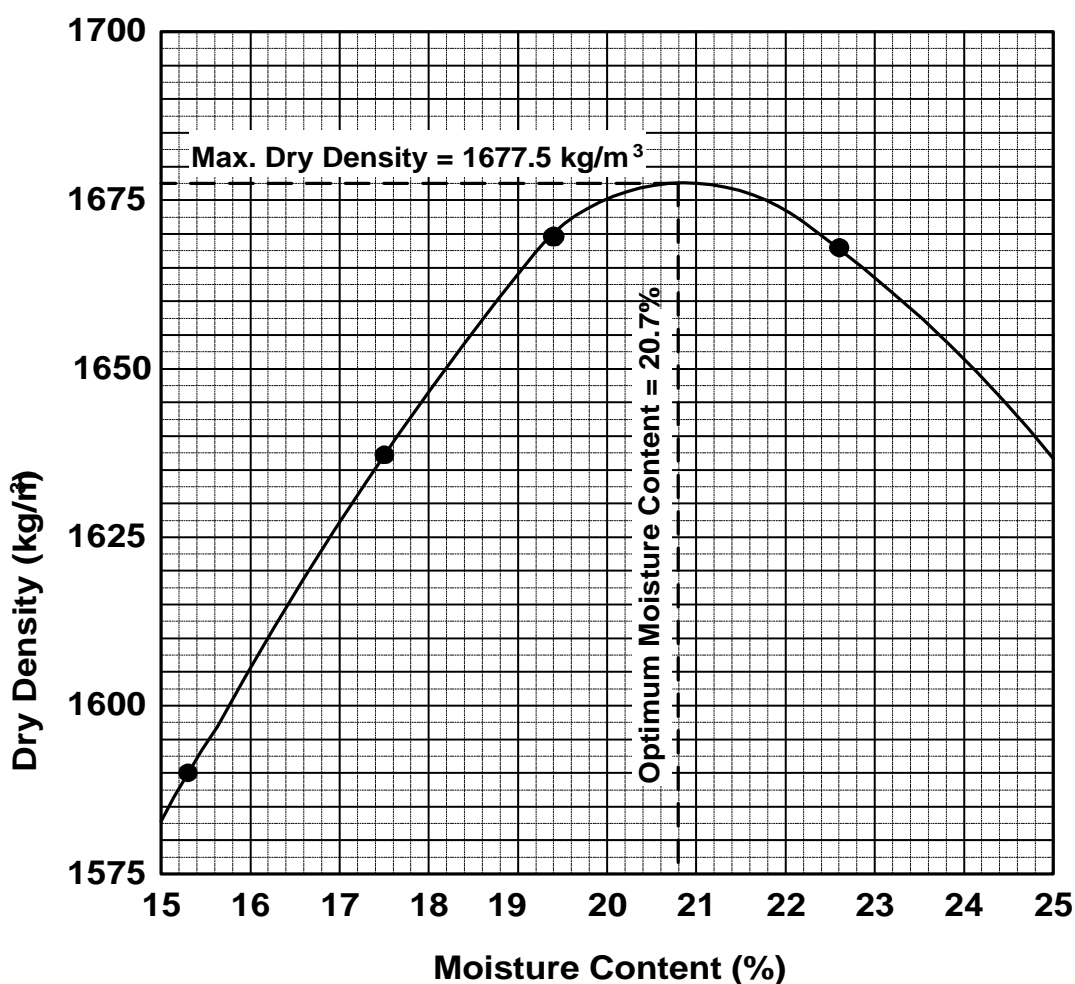


Figure 1 - The dry density to moisture content relationship is plotted and the "Moisture-Density Curve" is established. The maximum dry density and optimum moisture are determined from the peak of this curve.

TYPICAL TEST RESULTS

Typical maximum density and optimum moisture that can be expected as the result of a standard compaction test (AASHTO T 99) are given below. A modified compaction test (AASHTO T 180) will yield 10 to 15 percent higher maximum densities and 20 to 30 percent lower optimum moisture due to the greater compactive effort used (as described in Table 1).

Unified Soil Class	Description	Range of Max. Densities kg/m ³ (lbs/ft ³)	Range of Optimum Moisture (%)
CH	Highly plastic clays	1200-1680 (75-105)	19-36
CL	Silty clays	1520-1920 (95-120)	12-24
ML	Silts and clayey silts	1520-1920 (95-120)	12-24
SC	Clayey sands	1680-2000 (105-125)	11-19
SM	Silty sands	1760-2000 (110-125)	11-16
SP	Poorly-graded sands	1600-1920 (100-120)	12-21
SW	Well-graded sands	1760-2080 (110-130)	9-16
GC	Gravel, sand, clay mixes	1840-2080 (115-130)	9-14
GP	Poorly-graded gravels	1840-2000 (115-125)	11-14
GW	Well-graded gravels	2000-2160 (125-135)	8-11

Table 1 - Typical Values of maximum Density and Optimum Moisture for Common Types of Soil (AASHTO T 99)

EQUIPMENT



Soil-T99-3

Figure 2

Before beginning any procedure, you must first assemble all the equipment you will need to perform the test. You will need the following equipment per AASHTO T 99/T 180 as shown in

- ! Rammers: The difference between the two procedures (standard and modified) is the mass and freefall of the rammer used to compact the soil or soil and aggregate mixture in the mold and the number of layers placed into the compaction mold for compaction.

Differences Between Standard (T99) and Modified (T180) Moisture Density Tests		
	Standard	Modified
Rammers (Manual and Mechanical) Mass	2.495±0.009kg (5.5±0.02 lb)	4.536±0.009kg (10.00±0.02 lb)
Drop of Hammer to Soil Surface	305±2mm (12.00±0.06 in.)	457±2mm (18.00±0.06 in.)
Layers Placed when Filling Mold	3	5

Table 2. Differences between standard and modified moisture density tests.

- ! Mechanical compacting ram: If a mechanical compacting ram is used, it must be calibrated to produce results repeatable with the manual methods using ASTM method D2168. The percentage difference of maximum dry unit mass values for a single set of data (the same sample run through both manual and mechanical compaction procedures) may not exceed 2%. If this tolerance is exceeded, the mechanical hammer apparatus may need adjustment. In addition to this density check, the deformation characteristics of both manual and mechanical compacting must be checked using a lead deformation apparatus and lead test cylinders. Deformation is checked on a lot of lead cylinders and the percentage of average deformation difference resulting from manual and mechanical compaction methods must not exceed 2%. Refer to ASTM D2168 for detailed procedures when calibrating mechanical rammers to manual rammers.
- ! Compaction block, with a mass not less than 90 kg (200 lb).
- ! Molds: Depending on the method, either a 101.6 mm (4 in.) or a 152.4 mm (6 in.) mold, solid wall metal cylinder, with dimensions and capacities as shown in AASHTO T99 & T180, Figure 2. Molds that fail to meet manufacturing tolerances after continued service may remain in use provided those tolerances are not exceeded by more than 50%; and the volume of the mold, calibrated in accordance with Section 8 of AASHTO T19, is used in the calculations.
- ! Scales and balances, conforming to requirements of AASHTO M231 Class G20 and G2.
- ! Drying oven, capable of maintaining 110±5°C (230±9°F).
- ! Straightedge: At least 250mm (10 in.) length, made of hardened steel with one beveled edge. The straightedge is used to plane the surface of the soil even with the top of the mold. The straightedge may become worn with use and should be checked periodically. The straightedge should not be so flexible that it leaves a concave surface when trimming the soil from the top of the compacted sample.

- ! Engineering Curve
- ! Sieves: 50mm (2 in.), 19.0mm (3/4 in.), and a 4.75mm (No. 4) conforming to the requirements of AASHTO M92.
- ! Mixing Tools: Sample pans, spoons, scoops, trowels, used for mixing the sample with water.
- ! Containers: Corrosion resistant with close fitting lids to retain moisture content of prepared soil samples.
- ! Miscellaneous: Graduated cylinders for adding water.

COMMON TESTING ERRORS

- ! The wrong number of blows is delivered with the rammer.
- ! The lifts vary in thickness.
- ! The soil is not thoroughly mixed to achieve uniform moisture.
- ! The sample is not properly dried or the moisture content sample is improperly taken.
- ! The manual rammer is not held vertically when the blows are delivered.
- ! The mold is out of calibration tolerances.
- ! The compaction block is unstable.
- ! The compaction block is not of sufficient mass.
- ! The points are not plotted correctly on the graph.
- ! The rammer is not properly cleaned between uses.
- ! The mechanical rammer is out of calibration.
- ! The mechanical rammer has the wrong compaction face.
- ! The wrong mold is used for the test.
- ! The wrong rammer is used for the test.
- ! The drop of the rammer is incorrect.
- ! The manual rammer is not lifted to the full stroke.

METHODS

AASHTO T 99 and T 180 stipulates four distinct test methods for these procedures which are Method A, Method B, Method C, and Method D (Table 3). The method to be used should be indicated in the applicable specification.

	Method A	Method B	Method C	Method D
Mold Size	101.60mm (4 in.)	152.40mm (6 in.)	101.60mm (4 in.)	152.40mm (6 in.)
Material Size	Passing 4.75mm (No. 4)	Passing 4.75mm (No. 4)	Passing 19.0mm (3/4 in.)	Passing 19.0mm (3/4 in.)
Blows per Layer	25.000	56.000	25.000	56.000
Standard (T 99)	3 Layers; 2.495 kg (5.5 lb) rammer with/305 mm (12 in.) drop			
Modified (T 180)	5 Layers; 4.536 kg (10 lb) rammer with/457 mm (18 in.) drop			

Table 2. Moisture-Density Methods and Associated Mold Sizes.

Use caution when selecting the test method to be used. AASHTO test method designations are distinct from ASTM methods listed in D 698 and D 1557. ASTM also contains three Methods (A, B, or C) which correspond to different mold dimensions than the AASHTO counterparts.

The step by step procedures for AASHTO T 99 and T 180 are essentially the same. The differences in the two methods are the number of layers of soil used, the weight of the rammer and the drop of the rammer. AASHTO T 99 will always use 3 layers and a 2.495 kg (5.5 lb) rammer with 305 mm (12 in.) drop for all methods. AASHTO T 180 will always use 5 layers and a 4.536 kg (10 lb) rammer with 457 mm (18 in.) drop.

AASHTO stipulates for each method that material must pass the designated sieve (Table 3). Any material retained on the designated sieves is discarded, unless the oversize correction procedure is to be used, (See "Rock Replacement" below.)

SAMPLE PREPARATION

1. If the sample is wet, dry it in an oven not exceeding 60°C (140°F) until it becomes friable under a trowel. Aggregations in a friable soil sample will break apart easily. Avoid breaking apart the natural particles when breaking up the soil aggregations.
2. Sieve the sample over the specified sieve for the Method being performed (A and B use a 4.75mm (No. 4) sieve, C and D use the 19.0mm (3/4 in.). Discard any material retained on the specified sieve.

NOTE

Rock Replacement: It may be necessary to maintain the same percentage of coarse material in the lab sample as was found in the field. If rock replacement is required, the material to be tested should be screened through a 50 mm (2 in.) And 19 mm (3/4 in.) To ascertain the amount of material retained on the 19 mm (3/4 in.) Sieve. An equal mass of material which passes the 19 mm (3/4 in.) But retained on the 4.75 mm (No. 4) sieve is then obtained from the remaining portion of the sample. This material is recombined with the test sample prior to compaction. When this procedure is followed, it is necessary to prepare a larger quantity of material for testing.

3. Thoroughly mix the remaining sample. Obtain at least enough material to fill the mold when compacted and provide enough extra material to ensure adequate material for determination of moisture content and increase in density as more water is added.

NOTE

This method uses the same soil or soil-aggregate sample for each "point" on the density curve. If the soil or soil-aggregate mixture to be tested is a clayey material which will not easily mix with water or where the soil material is fragile and will break apart from the repeated blows of the compaction rammer, it may be necessary to prepare individual portions for each density point.

In most cases enough material should be sampled from the field to permit four individual "points" anticipated optimum moisture content, and then each subsequent "point" increased by 2% moisture. Optimum moisture content should be "bracketed" by the prepared samples in order to provide a more accurate moisture-density curve.

4. Prepare the sample(s) and mix with water to produce the desired moisture content. If the four "points" are prepared in advance make sure to store prepared material in moisture tight containers. The following example illustrates how to calculate the amount of water to be added to the soil or soil-aggregate material as a percentage of the sample's original mass.

A sample of 6.09 kg needs to be prepared with approximately 2% additional moisture; 6.09 kg is multiplied by 1.02% to yield a sample mass of 6.21 kg.

$$\begin{aligned}6.09 \times 1.02 &= 6.21 \text{ kg} \\6.21 - 6.09 &= 0.12 \text{ kg}\end{aligned}$$

Therefore, 0.12 kg of water should be added to bring the moisture content up by approximately 2%. Since water has a mass of one gram per milliliter, 120 mL of water should be added.

PROCEDURE

1. Record the mass of the mold and base plate (without the extension collar) in kilograms the nearest 5 grams.

NOTE:

While compacting the sample, make sure the mold rests on a rigid and stable foundation or base which will not move.

2. Place a representative portion of the sample into the mold (102 mm [4 in.]) diameter mold for Methods A and C, or a 152 mm (6 in.) diameter mold for Methods B and D) in order to fill it in three approximately equal layers to give a total compacted depth of about 127 mm (5 in.) (AASHTO T 99) or five approximately equal layers to give a total compacted depth of about 127 mm (5 in.) (AASHTO T 180).
3. Use the 2.495 kg (5.5 lb) rammer for standard moisture density test (AASHTO T 99) or with the 4.536 kg (10 lb) rammer for modified moisture density test (AASHTO T 180).
4. Apply the required number of blows to the specimen layer (25 blows for Methods A and C, 56 blows for Methods B and D).
5. When compacting the specimen using the manual rammer, uniformly distribute the blows over the entire surface area of the sample.

NOTE

- ▶ Do not lift the rammer and sleeve from the surface of the sample while compacting.
- ▶ Hold the rammer perpendicular to the sample and mold during compaction.

6. Repeat this Steps 1 through 5 for each subsequent layer.
7. Remove the extension collar from the mold and trim the sample even with the top edge of the mold using a straightedge. Remove any particles that lodged between the mold and the base plate or bolt holders. If there are voids in the surface of the compacted sample, fill them with loose soil collected from around the baseplate.
8. Weigh the mold with sample and record to the nearest 5 grams.
9. When using the 100 mm (4 in.) mold (Methods A and C) multiply the wet mass of the soil (mold mass with sample minus mold mass) in kilograms by 1060, and record the wet density of the soil, W_1 , in kilograms per cubic meter.

When using the 150 mm (6 in.) mold (Methods B and D) multiply the wet mass of the

soil (mold mass with sample minus mold mass) in kilograms by 471, and record the wet density of the soil, W_1 , in kilograms per cubic meter.

10. Remove the compacted soil or soil-aggregate sample from the mold and slice vertically through the center of the specimen. Obtain a representative sample from one of the cut faces, determine the moist mass immediately and record and dry in accordance with AASHTO T265 to determine moisture content.
11. Break up the remainder of the sample from mold until it is judged by eye to completely pass a 4.75 mm (No. 4) sieve for Methods A and B. When using Methods C or D, break up the particle aggregations until those particles which are agglomerated will completely pass a 19.0 mm (3/4 in.) sieve and 90% of the fines (eligible material) in the sample will pass a 4.75 mm (No. 4) sieve. Add the broken up sample to the remainder of the sample being used for the test.
12. Add additional water to the sample to increase the overall moisture content by about 2% (as described in Step 4 of Sample Preparation). The content should never be more than 4%. If separate density points were prepared prior to performing the procedure, skip this step. Continue compacting samples with moisture contents increasing by roughly 2% until there is a drop or no change in the calculated wet density.

$$w = 100 \left(\frac{a - b}{b} \right)$$

CALCULATIONS

1. Calculate the wet density of the material as follows:

Method A & C	$W_1 = (M_{ms} - M_m) \times 1060$
Method B & D	$W_1 = (M_{ms} - M_m) \times 471$

where: W_1 = Wet Density in kg/m³
 M_{ms} = Mass of the mold and sample in kg
 M_m = Mass of the mold in kg
1060 and **471** = Constants based on the size of the mold

2. Calculate the moisture content for each compacted sample by dividing the water content (loss between wet mass and dry mass of moisture sample) by the dry mass of the sample and multiplying by 100.

where: w = moisture content of sample
 a = wet mass of soil
 b = dry mass of soil

3. Calculate the dry density (W) for each compacted sample based on the corresponding Soil-T99-9

moisture sample for each compacted specimen.

where: **W** = dry density in kg/m³ or pcf
w = moisture content of sample
W₁ = wet density in kg/m³ or pcf

4. Plot each compaction point for dry density on graph paper with density on the x-axis and moisture content on the y-axis as shown on Figure 3.
5. Form a smooth line using the engineer's curve by connecting the plotted points to form two curves. As close as possible to the intersection, round the peak to form a smooth, continuous line.
6. The moisture content corresponding to the peak of the curve will be termed the "optimum moisture content."
7. The dry density corresponding to the peak of the curve will be termed "maximum dry density."

Example Calculation

The following example moisture density relationship (Table 4) is calculated as a Modified, Method A (Large Hammer, Small Mold). Remember that the mass of the wet soil needs to be expressed per the unit volume of the mold used. The mass of the wet soil in kilograms is multiplied by 1060 to determine the wet

$$W = \frac{W_1}{w + 100} 100$$

density in kg/m³.

Point No.	1	2	3	4
Mass of mold and soil (kg)	6.065	6.130	6.190	6.185
Mass of mold (kg)	4.295	4.295	4.295	4.295
Mass of wet soil (kg)	1.770	1.835	1.895	1.890
Wet Density (kg/m ³)	1876.2	1945.1	2008.7	2003.4
Moisture Contents				
A=Mass of container and wet soil	373.5	397.5	385.2	387.3
B=Mass of container and dry soil	336.9	354.9	339.7	338.9
C=Mass of container (g)	115.2	123.2	115.4	122.8
w=Moisture content (%)	16.5	18.4	20.3	22.4
W=Dry density (kg/m ³)	1610.5	1642.8	1669.7	1636.8

Table 4 - Modified Method A Moisture-Density Relationship Computation.

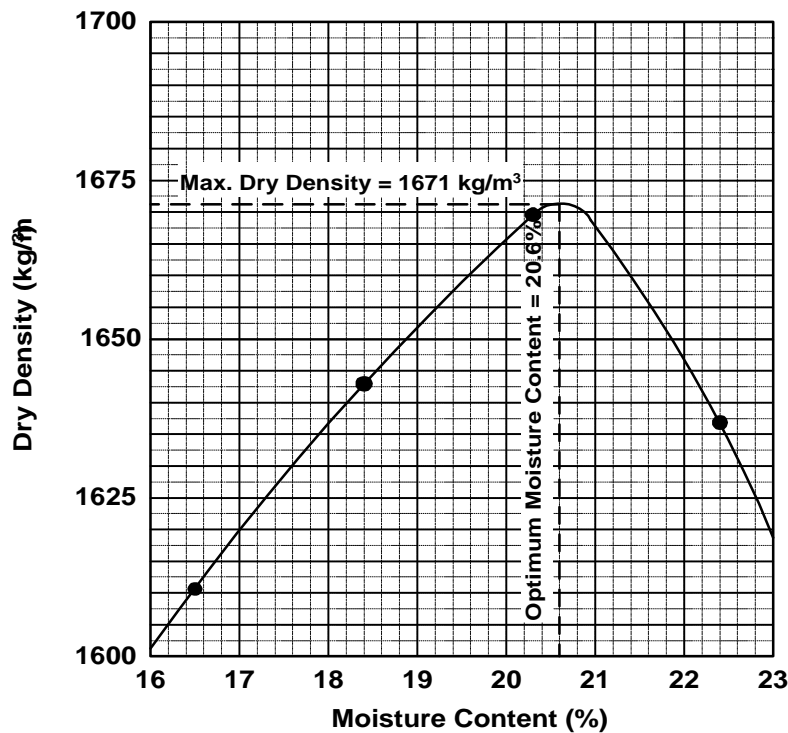


Figure 3. Graphic plot of the moisture-density relationship in Table 4, illustrating determination of maximum density and optimum moisture.

GLOSSARY

Compaction	- The reduction of voids in a soil mass. The densification of the soil mass by applying a force such as the delivered by the rammer.
Compaction Effort	- The force applied to achieve compaction of a soil mass. In the laboratory, the rammer used in this test procedure produces the compaction effort. Compaction effort is increased by increasing the mass, increasing the distance the mass is dropped, increasing the number of drops or reducing the thickness of the layer being compacted.
Density	- The mass of the soil divided by the volume.
Dry Density	- The density of the soil corrected for moisture content.
Homogenous	- Of uniform structure and composition throughout.

Maximum Density	- The dry density corresponding to the peak of the moisture-density curve. The highest density that can be achieved for a particular soil using a particular compaction effort. Also referred to as “maximum dry density.”
Maximum dry Density	- See “maximum density”
Moisture Content	- The ratio, expressed as a percentage, of the mass of the water in a given soil mass to the mass of the solid particles. The mass of the soil remaining after oven-drying is used as the mass of the solid particles.
Moisture-Density Curve	- A smooth line connecting the points obtained from this test procedure when plotted on a graph with moisture on the x-axis and density on the y-axis.
Optimum Moisture Content	- The moisture content corresponding to the peak of the moisture-density curve. The moisture content at which the maximum density can be achieved.
Percent Compaction	- The ratio, expressed as a percentage, of the density of a soil to its maximum density.

Density of Soil-In Place
by
The Sand Cone Method
AASHTO T 191



Developed by
FHWA Multi-Regional Soils Training & Certification Group

August, 1999

NOTE

Successful completion of the following training materials, including examination and performance evaluations are prerequisites for this training package

- AASHTO T 99 and T 180 - Laboratory Determination of Moisture-Density Relations of Soils

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DENSITY OF SOIL IN-PLACE BY THE SAND-CONE METHOD

This test uses the sand cone apparatus to determine the in-place density of soil or soil aggregate mixtures. Density is used to calculate the compaction levels of the constructed soil or soil aggregate layers. Compaction is densifying a material by a process of pressing the individual soil grain particles more closely together. Compaction or densification is usually accomplished by mechanical compactor devices (sheep foot compactor, vibratory compactor). Proper compaction improves the engineering properties of the soil mass. Density is a function of mass (weight) divided by its volume. Percent density is the ratio of the in-place density to the maximum (target) density as determined in the laboratory according to standard testing procedures.

Summary

Prior to testing, calibrations must be done to determine the volume of the sand cone apparatus, the sand density, and the weight of sand in the large cone. To determine the in-place density using the sand cone first: excavate a hole as deep as the thickness of the compacted lift. Remove all material and weigh. After weighing, use a representative sample to determine the moisture content. Then measure the volume of the hole, which is the volume of the soil sample in its undisturbed condition before removal, is measured by filling the hole with sand whose unit mass (weight) is known. The mass of the sand required to fill the hole is converted into volume. The mass of the soil removed from the hole divided by the volume of the hole is the wet density of the soil.

Common Testing Errors

- ▶ Equipment not calibrated properly
- ▶ Soil weighed contained stones larger than No 4.75 mm (No 4)
- ▶ Vibrating jar while sand is flowing into test hole
- ▶ Moisture content not properly determined

Equipment needed

Before beginning any procedure, you must first assemble all the equipment you will need to perform the test. To determine in-place density using a sand-cone, you will need:

- ▶ Density apparatus, consisting of a 4 L (1 gal) jar and a detachable appliance consisting of a cylindrical valve with an orifice 12.7mm ($\frac{1}{2}$ in.) in diameter and having a small funnel continuing to a standard G mason jar top on one end and a large funnel on the other end. The valve shall have stops to prevent rotating the valve past the completely open or completely closed positions (AASHTO T 191, 2.1). (See Figure 1)

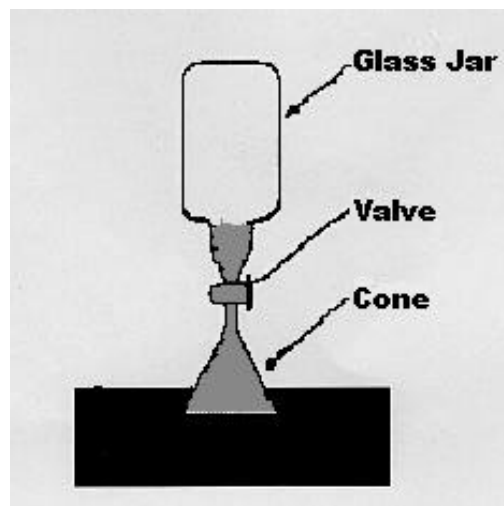


Figure 1 - Sand Cone Device

- ▶ Sand: Should be a clean, non-cementitious sand with few or no particles passing the 0.075mm (No. 200) sieve, and none retained on the 2.00 mm (No. 10) sieve. AASHTO T 191 requires that the bulk density of the sand be measured several times to ensure that the sand does not have a variation in bulk density greater than 1 percent.
- ▶ Balances: AASHTO M 231, Class G20 (over 5 Kg through 20 Kg principle sample mass, sensitivity of 5 g or 0.1%); and AASHTO M231 Class G (2 Kg or less, sensitivity of 0.1 g or 0.1%).
- ▶ Drying equipment: Suitable for drying moisture content samples, usually a hot plate or Sterno stove in the field.
- ▶ Miscellaneous equipment: Digging tools for test hole, which might include a small pick, chisels, spoons, scoops, etc.; suitable container for drying moisture sample (small pan), buckets or canvas bags to retain density sample, cache of density sand, thermometer for water temperature determination (if calibrating cone in field), brush for fines.

Equipment Preparation

Determine the volume of the jar and attachment up to and including the volume of the valve orifice.

1. Screw the metal top on the empty jar , weigh and record the mass. It is advisable to use a rubber gasket, such as a Mason canning ring, to prevent the water used in the calibration from leaking. The gasket should remain on the jar at all times. Removal will change the volume.
2. Place the apparatus in the upright position, open valve and pour water through the funnel into the jar. When water level is slightly above top of valve, close the valve.

Note:

Use water at a temperature of 65 to 68° F (18.3 to 20° C).

3. Carefully blot up the excess water above valve, wipe off any water which may have spilled on the jar.
4. Weigh and record the mass.
5. Weight of water equals mass of the jar filled with water minus the mass of the empty jar.

$$\text{Volume (ft}^3\text{)} = \frac{\text{Weight of Water(pounds)}}{62.43(\text{Density of Water})} \quad (\text{Pounds})$$

$$\text{Volume (ft}^3\text{)} = \frac{\text{Mass of Water(Kg)}}{1000(\text{Water Density})} \quad (\text{Meters})$$

Perform the above steps a minimum of three times, or as necessary to obtain consistent results.

Determine the bulk density of the sand (W_1) to be used in the test.

1. Place the empty apparatus upright on a firm, level surface, close the valve, and fill the funnel with sand.
2. Open the valve and, keeping funnel at least half full of sand, fill the apparatus. Close the valve sharply and empty excess sand.
3. Weigh apparatus with the sand and determine the net mass of sand by subtracting the mass of the apparatus.
4. Calculate the bulk density of the sand as follows:

$$W_1 = \frac{62.427 \times W_2}{V_1}$$

where:

W_1 = bulk density of the sand in pound per cubic foot
 W_2 = grams of sand required to fill the apparatus
 V_1 = volume of the apparatus in cubic centimeters

Calculate the bulk density of the sand to the nearest 0.1 pcf. If a secondary apparatus is used then use the volume of the secondary apparatus in place of V_1 .

5. Special considerations when determining the bulk density of the sand: avoid any vibration of the sand during the mass/volume calculation. Vibration could cause the bulk density of the sand to be higher than normal.

Check the bulk density of the sand regularly (at least once a day before taking tests). Slight changes in moisture or degradation of the sand during storage and transport may affect the sand density determination. It is also acceptable to determine the bulk density of the sand using other volumetric containers, provided that the bulk density as determined by these other methods is shown to be equal the bulk density of the sand as determined by the sand cone.

Example calculation: Determining Bulk Density of Sand

Volume of Apparatus is 0.075 cubic feet, grams of sand required to fill apparatus is 3332.8 grams.

$$W_1 = \frac{62.427 \times W_2}{V_1}$$

where:

W_1 = bulk density of the sand in pound per cubic foot

W_2 = grams of sand required to fill the apparatus

V_1 = volume of the apparatus in cubic centimeters

$$W_1 = (62.427 \times 3332.8) / 2123.8$$

$$W_2 = 208056.7 / 2123.8$$

$$V_1 = 97.9 \text{ pcf}$$

Determining the Mass of Sand Required to Fill the Cone

1. Put sand into the apparatus and close the valve.
2. Invert the apparatus on a clean, level, surface so that the cone is facing down. If a base plate is used normally during testing then it must be used during the calibration phase as well.
3. Open the valve and allow the sand to flow until it stops. Close the valve sharply and weight the apparatus with the remaining sand in the jar. Determine the loss of sand and record as the weight of sand required to fill the cone.
4. Replace the sand used for this determination and close the valve. The sand cone is now ready and calibrated for use.
5. Considerations when determining the amount of sand required to fill the cone: when testing soils that will not permit a uniform and level testing area, AASHTO T 191 Note 7 recommends measuring the mass of sand required to fill the cone and the unbounded testing surface in lieu of measuring just the sand required to fill the cone. This is a special situation and is used to compensate for sand loss to uneven surfaces.

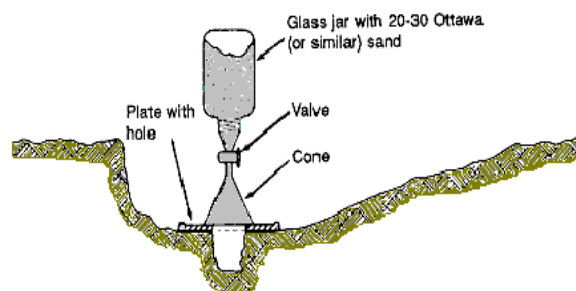


Figure 2 - Sand Cone filled with Sand

Finding the Mass of sand in the hole (Figure 2)

Procedure

1. Make sure the jar is filled with enough sand to fill the hole volume and the cone. Weigh the apparatus with the sand prior to use. This mass will be used to determine a loss of sand after it has been used to fill the excavated hole and cone.
2. Prepare the surface of the location to be tested so that it is a level plane.
3. Seat the inverted apparatus on the prepared plane surface and mark the outline of the funnel. Alternately, place the base plate on the level surface.

NOTE

Step 4 not listed in AASHTO T 191, adapted from ASTM D 1556-90.

4. Remove the soil from the area outlined by the cone or within the area bounded by the base plate hole. Take care not to disturb the soil that will bound the hole while removing the soil from the volume of the test hole. The volume of the hole is dependent upon maximum particle size (Table 2) of the material being tested in conformance to AASHTO T191, Table 1. A larger jar and cone may be needed when the volume exceeds 0.1 cubic feet.

Maximum Particle Size		Minimum Test Hole Volume	Minimum Mass for Moisture Content, g
mm	alternate		
4.75	No. 4	0.025	100
12.5	½ in.	0.05	250
25	1 in.	0.075	500
50	2 in.	0.1	1000

Table 2. Minimum volume of test hole for maximum particle size.

The walls of the hole should slope slightly inward and the bottom should be reasonably flat or concave. The hole should be kept as free as possible of pockets, overhangs, and sharp obtrusions since these affect the accuracy of the test. Soils that are essentially granular require extreme care and may require digging a conical shaped test hole. Place all excavated soil and any soil loosened during digging in a moisture tight container that is marked to identify the test number. Take care to avoid the loss of any materials. Protect this material from any loss of moisture until the mass has been determined and a specimen has been obtained for a water content determination (ASTM D 1556, 71.5).

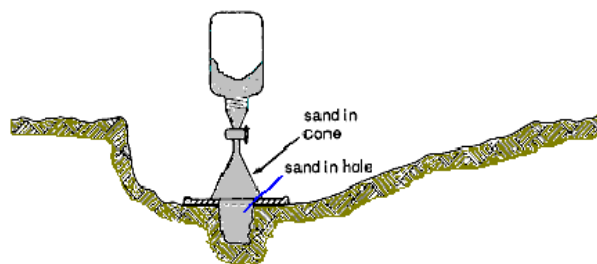


Figure 3 - Hole filled with sand

5. Weigh and record the material removed from the test hole. Retain a representative portion of the sample to determine the moisture content of the soil, making sure that the moisture sample conforms to the minimum mass requirements in Table 2. Determine the moisture content of the soil using AASHTO T 265 or another acceptable rapid dry method.
6. Seat the apparatus in a hole or on the base plate and open the valve. Allow the sand to flow from the cone, filling the hole and the cone apparatus. Once the sand has ceased flowing, sharply close the valve. There should be no vibration in the immediate area during this operation.
7. Weigh the apparatus with the remaining sand and subtract this from the original weight of the apparatus filled with sand. This is the mass of sand used for the test. Subtract the mass of the sand previously determined to fill the cone from the mass of the sand used for the test. This is the mass of sand used to fill the excavated hole.

Calculations

Calculate the moisture content (w) and the dry mass of the material removed from the test hole (W_6) as follows:

$$W = \frac{(W_3 - W_4) \times 100}{W_4}$$

$$W_6 = \frac{0.2205 \times W_5}{W + 100}$$

where:

w = percentage of moisture content, in material for test hole

W_3 = moist mass of moisture sample, in grams

W_4 = dry mass of moisture sample, in grams

W_5 = moist mass of the material from the test hole, in grams

W_6 = dry mass of material from the test hole, in pounds.

Calculate the moisture content to the nearest 0.1 percent.

Calculate the dry mass of the material removed from the test hole to the nearest 0.01 lb.

Calculate the dry density (W) of the material as follows:

$$V = \frac{W_7 - W_8}{453.6 \times W_1}$$

$$W = \frac{W_6}{V}$$

where:

V = volume of test hole, in cubic feet

W_7 = grams of sand used

W_8 = grams of sand in funnel

W = dry density of the tested material, in pcf

Calculate the in-place dry density of the material tested to the nearest 0.1 pcf

Determining Percent Compaction (%D)

Determine the Percent of Compaction (percentage of the maximum density as determined by the laboratory moisture density relation) by dividing the field result by the laboratory result and multiplying by 100.

$$\%D = \frac{W \times 100}{L}$$

where:

%D = percentage of maximum dry density as determined by AASHTO T 99 or T 180

W = dry density of tested material, in pcf

L = laboratory maximum dry density as determined by AASHTO T 99 or T 180

Example Calculations

Determining moisture content (w) and dry mass of material (W₆) from hole

Moist mass of moisture sample is 271.6 g, dry mass of moisture sample is 257.9 g, moist mass of sample from test hole is 3234.5 g.

$$W = \frac{(W_3 - W_4) \times 100}{W_4}$$

$$W_6 = \frac{0.2205 \times W_5}{W + 100}$$

where:

w = percentage of moisture, in material for test hole

W₃ = moist mass of moisture sample, in grams

W₄ = dry mass of moisture sample, in grams

W₅ = moist mass of the material from the test hole, in grams

W₆ = dry mass of material from the test hole, in pounds.

$$w = (271.6 - 257.9) \times 100 / 257.9$$

$$w = 5.3$$

$$W_6 = (0.2205 \times 2864.9) / 5.3 + 100$$

$$W_6 = (631.7) / 105.3$$

$$W_6 = 6.00 \text{ lb}$$

Determining Dry Density (W) of Material

2150.0 grams of sand were used to fill the hole, 240.0 grams of sand filled the funnel.

$$V = \frac{W_7 - W_8}{453.6 \times W_1}$$

$$W = \frac{W_6}{V}$$

where:

V = volume of test hole, in cubic feet

W₇ = grams of sand used

W₈ = grams of sand in funnel

W = dry density of tested material, in pcf

$$V = (2150 - 240) / (4536 \times 97.9)$$

$$V = 0.043 \text{ ft}^3$$

$$W = 6.00 / 0.043$$

$$W = 139.5 \text{ pcf}$$

Determining Percent Compaction

Optimum laboratory dry density as determined by AASHTO T 99 or T 180 is 142.1 pcf.

$$\%D = \frac{W \times 100}{L}$$

where:

%D = percentage of maximum dry density as determined by AASHTO T 99 or T 180

W = dry density of tested material, in pcf

L = laboratory maximum dry density as determined by AASHTO T 99 or T 180

$$\%D = (W / L) 100$$

$$\%D = (139.5 / 142.1) 100$$

$$\%D = (0.982) 100$$

$$\%D = 98.2$$

Remember that the final density will be corrected for any oversize particles as outlined in:
Correction for Coarse Particles in the Soil Compaction Test, AASHTO T 224.

Glossary

Compaction	The field process of pressing the individual soil grain particles closer together by means of mechanical devices
Compaction Effort	The force required to achieve the required compaction level
Density	The mass of the soil divided by the volume
Dry Density	The density of the soil corrected for moisture content. Also referred to as "in-place density"
Maximum Density	The highest density obtained for a particular soil type using a particular compaction effort. Corresponding peak on a moisture-density curve as determined in the laboratory
Optimum Moisture	The moisture content at which maximum density can be obtained
Percent Density	The ratio expressed as a percentage of the dry density to the maximum density

MOISTURE-DENSITY RELATIONS OF SOILS

FAMILY OF CURVES -- ONE POINT METHOD

AASHTO T 272



Developed by
FHWA Multi-regional Soils Training & Certification Group

NOTE

Successful completion of the following training materials, including examination and performance evaluation are prerequisites for this training package.

- ▶ AASHTO T 190, Density of Soil In-Place by the Sand-Cone Method
or
- ▶ AASHTO T 265, Laboratory Determination of Moisture Content of Soils
- ▶ AASHTO T 99, The Moisture - Density Relations of Soils Using a 2.5 kg (5.5 lb) Rammer and a 305 mm (12 in.) Drop.

To use this procedure, the student must have a Family of Curves produced in accordance with the Appendix procedure outlined in AASHTO T 272 relevant to the soils to be encountered .

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FAMILY OF CURVES--ONE POINT METHOD

The Family of Curves is a conversion tool developed to provide maximum dry density and optimum moisture for soils commonly used in highway construction. The curves show the moisture/density relationships of various soils or soils containing aggregate so that if the wet density and moisture content of a soil is known, its maximum dry density and optimum moisture can be read from the curve for that soil.

Soils are composed of various combinations of sand, silt, and clay. Where a material fits on the Family of Curves depends on the composition of the material. Sandy or silty soils fit on the curves with higher maximum densities, clay soils fit those curves with lower maximum densities. Since sands do not hold water, the maximum density of sandy soil will occur at a lower percent moisture content than for soils which contain fines.

SUMMARY OF TESTING

Because of the wide variation in the soils encountered on any geographical area, it is difficult for the inspector who performs the in-place density tests to identify the soil at a specific site and relate it to the proper laboratory maximum density test. A method has been developed to enable the inspector to determine in the field the maximum density of soil encountered for each in-place density test. It consists of compacting the soil in a standard AASHTO T 99 compaction mold, determining its wet density and moisture content, and using this data with a Family of Curves to determine the maximum dry density. This procedure is commonly referred to as the One-Point Method.

TYPICAL TEST RESULTS

This test provides the same results as a AASHTO T 99 Moisture – Density Relations of Soils Using 2.5 kg Rammer and a 305 mm drop.

COMMON TESTING ERRORS

- ▶ This method can be used for any soil that develops a classic parabolic “Proctor Curve.”
It is not applicable for free draining granular materials.
- ▶ Failure to protect samples from changes in moisture content will affect the results of this test.
- ▶ Not placing the mold on a substantial base, 90 kg (200 lb) of concrete or equivalent, while compacting the specimen will cause loss of compactive effort and adversely affect the results.
- ▶ Level all scales before weighing.
- ▶ Protect scales from drafts that would affect the accuracy of weighing.
- ▶ Use care in reading the graphs used in this method, it is very easy to misinterpret the data. Read and record, then read again.

TEST METHODOLOGY

Equipment

Before beginning any procedure, you must first assemble all the equipment you will need to perform the test. For this procedure you will need the following.

- ▶ A 101.6-mm (4 in.) mold, having a capacity of $0.000943 \pm 0.000008 \text{ m}^3$ ($0.0333 \pm 0.0003 \text{ ft.}^3$) with an internal diameter of $101.60 \pm 0.41 \text{ mm}$ ($4.000 \pm 0.016 \text{ in.}$) And a height of $116.43 \pm 0.13 \text{ mm}$ ($4.584 \pm 0.005 \text{ in.}$).
- ▶ A 152.4 mm (6 in.) mold, having a capacity of $0.002124 \pm 0.000021 \text{ m}^3$ ($0.07500 \pm 0.00075 \text{ ft.}^3$) with an internal diameter of $152.40 \pm 0.66 \text{ mm}$ ($6.000 \pm 0.026 \text{ in.}$) and a height of $116.43 \pm 0.13 \text{ mm}$ ($4.584 \pm 0.005 \text{ in.}$).
- ▶ A metal rammer with a mass of $2.495 \pm 0.009 \text{ kg}$ ($5.5 \pm 0.02 \text{ lb}$), and having a flat circular face of 50.8 mm (2.000 in.) diameter with a manufacturing tolerance of $\pm 0.25 \text{ mm}$ (0.01 in.) and a controlled height of fall of $305 \text{ mm} \pm 2 \text{ mm}$ ($12.00 \pm 0.06 \text{ in.}$). The rammer shall be equipped with a guide-sleeve to control the height of the drop. The guide-sleeve shall have a least 4 vent holes, no smaller than 9.5 mm (3/8 in.) diameter spaced approximately 90 degrees (1.57 rad) apart and approximately 19 mm (3/4 in.) from each end; and shall provide sufficient clearance so the free fall of the rammer shaft and head is unrestricted.
- ▶ One straightedge 250 mm (10 in.) long with a beveled edge and at least one longitudinal surface.
- ▶ Sieves, 50 mm (2 in.), 19.0 mm (3/4 in.), and 4.75 mm (No. 4).
- ▶ Balances or Scales conforming to AASHTO M231
- ▶ A set of Typical Moisture-Density Curves
- ▶ Supply of clean water.
- ▶ Miscellaneous tools such as mixing pans, trowel, putty knife and a plastic or glass bottle with a sprinkling cap.
- ▶ Sample extruder consisting of a hydraulic jack and frame to remove compacted samples from the mold. Optional item.
- ▶ A thermostatically controlled drying oven capable of maintaining a temperature of $110 \pm 5^\circ\text{C}$ ($230 \pm 9^\circ\text{F}$) for drying moisture samples.

Method "A" Procedure

SAMPLE

Remove approximately 3.2 kg of representative soil from the test site for use in this procedure, after performing the in-place density test. If the Sandcone Method was used, be careful not to contaminate the sample with silica sand. Remove oversize material from this sample using the 4.75 mm sieve, by passing the entire sample over the sieve and separating the material into that which is retained on the sieve and that which passes the sieve. Test the material, which passed the sieve and discard the retained material. Record on the test data sheet "Test performed on material passing 4.75 mm sieve."

PROCEDURE

Thoroughly mix the selected sample with sufficient water to dampen approximately 4 percentage points below optimum moisture content. Greater accuracy in the determination of the maximum density will result as the moisture content approaches optimum moisture content. **Moisture content of the sample should never exceed the optimum water content.**

Form a specimen by compacting the prepared soil in the 101.6 mm mold (with the collar attached) in three approximately equal layers to give a total compacted depth of about 125 mm. Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 305 mm inches above the soil surface when a sleeve-type rammer is used. During compaction, the mold shall rest firmly on a dense, uniform, rigid and stable foundation. (A block of concrete, with a mass of not less than 90 kg supported by a relatively stable foundation; a sound concrete floor: and for field application, such surfaces as found in concrete box culverts, bridges, and pavements will meet this last requirement.)

Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge. Determine the mass of the mold and wet soil by weighing them in kilograms to the nearest 5 grams.

Subtract the mass of the mold from the mass of the soil and mold combined. Multiply the mass of wet soil and record the result as wet density, W_1 , in kilograms per cubic meter, of compacted soil.

Remove the material from the mold and slice vertically through the center. Take a representative sample from one of the cut faces, weighing not less than 100 grams and determine the moisture content. For tests run in conjunction with a nuclear density gage, the moisture content from that test may be used for this purpose, if allowed by local specification.

Method "B" Procedure

SAMPLE

Select a representative sample in accordance with Section 1.1, except that it shall have a mass of approximately 7 kg.

PROCEDURE

Follow the procedure as described for Method A in Section 2, except for the following: Form a specimen by compacting the prepared soil in the 152.4 mm mold (with the collar attached) in three approximately equal layers to give a total compacted depth of about 125 mm. Compact each layer by 56 uniformly distributed blows from the rammer dropping free from a height of 305 mm above the soil surface when a sleeve-type rammer is used. During compaction, the mold shall rest firmly on a dense uniform, rigid and stable foundation. (A block of concrete, with a mass of not less than 90 kg supported by a relatively stable foundation; a sound concrete floor: and for field application, such surfaces as found in concrete box culverts, bridges, and pavements will meet this last requirement.)

Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge. Determine the mass of the mold and wet soil by weighing them in kilograms to the nearest 5 grams and record the mass.

Subtract the mass of the mold from the mass of the soil and mold combined. Multiply the mass of wet soil by and record the result as wet density, W_1 , in kilograms per cubic meter, of compacted soil.

Remove the material from the mold and slice vertically through the center. Take a representative sample from one of the cut faces, weighing not less than 100 grams and determine the moisture content. For tests run in conjunction with a nuclear density gage, the moisture content from that test may be used for this purpose, if allowed by local specification.

Method "C" Procedure

This method can be used for any soil that develops a classic parabolic "Proctor Curve." It is not applicable to free draining granular materials.

SAMPLE

Remove approximately 5 kg of representative soil from the test site for use in this procedure, after performing the in-place density test. If the Sand cone Method was used, be careful not to contaminate the sample with silica sand. Remove oversize material from this sample using the 19.0 mm sieve, by passing the entire sample over the sieve and separating the material into that which is retained on the sieve and that which passes the sieve. Test the material, which passed the sieve and discard the retained material. Record on the test data sheet "Test performed on material passing 19.0 mm sieve."

PROCEDURE

Thoroughly mix the selected sample with sufficient water to dampen approximately 4 percentage points below optimum moisture content. Greater accuracy in the determination of the maximum density will result as the moisture content approaches optimum moisture content. **Moisture content of the sample should never exceed the optimum water content.**

Form a specimen by compacting the prepared soil in the 101.6 mm mold (with the collar attached) in three approximately equal layers to give a total compacted depth of about 125 mm. Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 305 mm above the soil surface when a sleeve-type rammer is used. During compaction, the mold shall rest firmly on a dense uniform, rigid and stable foundation. (A block of concrete, with a mass of not less than 90 kg supported by a relatively stable foundation; a sound concrete floor: and for field application, such surfaces as found in concrete box culverts, bridges, and pavements will meet this last requirement.)

Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge. Determine the mass of the mold and wet soil by weighing them in kilograms to the nearest 5 grams and record the mass.

Subtract the mass of the mold from the mass of the soil and mold combined. Multiply the mass of wet soil by 1060 and record the result as wet density, W_1 , in kilograms per cubic meter, of compacted soil.

Remove the material from the mold and slice vertically through the center. Take a representative sample from one of the cut faces, weighing not less than 100 grams and determine the moisture content. For tests run in conjunction with a nuclear density gage, the moisture content from that test may be used for this purpose, if allowed by local specification.

Method "D" Procedure

This method can be used for any soil that develops a classic parabolic " Proctor Curve." It is not applicable to free draining granular materials.

SAMPLE

Select a representative sample in accordance with Section 5.1, except that it shall have a mass of approximately 11 kg.

PROCEDURE

Follow the procedure as described for Method C in Section 7, except for the following: Form a specimen by compacting the prepared soil in the 152.4 mm mold (with the collar attached) in three approximately equal layers to give a total compacted depth of about 125 mm. Compact each layer by 56 uniformly distributed blows from the rammer dropping free from a height of 305 mm above the soil surface when a sleeve-type rammer is used. During compaction, the mold shall rest firmly on a dense uniform, rigid and stable foundation. (A block of concrete, with a mass of not less than 90 kg supported by a relatively stable foundation; a sound concrete floor: and for field application, such surfaces as found in concrete box culverts, bridges, and pavements will meet this last requirement.)

Following compaction, remove the extension collar, carefully trim the compacted soil even with the top of the mold by means of the straightedge. Determine the mass of the mold and wet soil by weighing them in kilograms to the nearest 5 grams and record the mass.

Subtract the mass of the mold from the mass of the soil and mold combined. Multiply the mass of wet soil and record the result as wet density, W_1 , in kilograms per cubic meter, of compacted soil.

Remove the material from the mold and slice vertically through the center. Take a representative sample from one of the cut faces, weighing not less than 100 grams and determine the moisture content. For tests run in conjunction with a nuclear density gage, the moisture content from that test may be used for this purpose , if allowed by local specification.

Calculations

See T 99, Section 11.

Maximum Density and Optimum Moisture Content Determination

To undertake the use of this procedure, the user must have a Family of Curves produced in accordance with the Appendix procedure outlined in AASHTO T 272 relevant to the soils anticipated to be encountered in the geographical area.

With the dry mass and moisture content calculated in Section 5.1, plot those values on the Family of Curves. (see Figure 1)

If the one-point falls on one of the curves in the Family of Curves, the maximum dry mass and optimum moisture content defined by that curve shall be used.

NOTE

In order to ensure that you have correctly identified the curve that matches the soil, the point must fall near the curve peak (no more than 4% below optimum moisture content). Note, that while AASHTO allows the point to fall at a 4% deviation from the optimum moisture content, many agencies have tighter restrictions. If the point falls on the dry side below the acceptable range, the moisture content of the soil is not high enough. Repeat the test with a fresh sample of the same material at a higher moisture content. Estimate the amount of moisture needed to bring the soil to the peak of the curve. With experience, you will be able to do this easily. Be careful. You do not want to add so much water that you will have to dry the material and repeat the test. Rarely, the point may fall on the wet side of the curve's peak. If this happens, dry the material and repeat the test. Add moisture using trial and error.

If the one-point falls within the family but not on a curve, a new curve shall be drawn through the plotted one-point parallel and in the same general shape with the nearest curve on the family of curves. the maximum dry mass and optimum moisture content as defined by that new curve shall be used.

If the one-point plotted within or on the family of curves does not fall in the range of 80 to 100 percent of optimum moisture content, compact another specimen, using the same material, at an adjusted moisture content that will place the one-point within that range.

Report

The method used (Method A, B, C, and D).

The optimum moisture content as a percentage to the nearest whole number.

The maximum mass to the nearest 0.5 kg/m³

In Methods C & D indicate if the material retained on the 19.0 mm sieve was removed or replaced.

GLOSSARY

Compaction	- The reduction of voids in a soil mass. The densification of the soil mass by applying a force such as the delivered by the rammer.
Compaction Effort	- The force applied to achieve compaction of a soil mass. In the laboratory, the rammer used in this test procedure produces the compaction effort. Compaction effort is increased by increasing the mass, increasing the distance the mass is dropped, increasing the number of drops or reducing the thickness of the layer being compacted.
Density	- The mass of the soil divided by the volume.
Dry Density	- The density of the soil corrected for moisture content.
Homogenous	- Of uniform structure and composition throughout.
Maximum Density	- The dry density corresponding to the peak of the moisture-density curve. The highest density that can be achieved for a particular soil using a particular compaction effort. Also referred to as "maximum dry density."
Maximum dry Density	- See "maximum density"
Moisture Content	- The ratio, expressed as a percentage, of the mass of the water in a given soil mass to the mass of the solid particles. The mass of the soil remaining after oven-drying is used as the mass of the solid particles.
Moisture-Density Curve	- A smooth line connecting the points obtained from this test procedure when plotted on a graph with moisture on the x-axis and density on the y-axis.
Optimum Moisture Content	- The moisture content corresponding to the peak of the moisture-density curve. The moisture content at which the maximum density can be achieved.
Percent Compaction	- The ratio, expressed as a percentage, of the density of a soil to its maximum density.

DENSITY AND MOISTURE CONTENT
OF SOIL-AGGREGATE
BY
NUCLEAR METHODS
(SHALLOW DEPTH)

AASHTO T 238 & T 239



Developed
by
FHWA Multi-Regional Soils & Certification Group

August, 1999

NOTE

Successful completion of the following training materials, including examination and performance evaluations are prerequisites for this training package.

- ▶ AASHTO T 99, Laboratory Determination of Moisture-Density Relations of Soils
- ▶ AASHTO T 191, Density of Soil In-Place by Sand-Cone Method

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DENSITY AND MOISTURE CONTENT OF SOIL AND SOIL-AGGREGATE IN-PLACE BY NUCLEAR METHODS(SHALLOW DEPTH)

Density is a function of mass (weight) divided by volume. The more closely pressed together the individual particles of a quantity of material are, the more dense it is. The farther apart they are, separated by air spaces (voids), the less dense the material is. When the individual particles of the same mass (weight) of material are pressed tightly together (compacted), the mass (weight) takes up less volume than when the particles are farther apart.

In order to ensure that the embankment, base course, or other earthwork structure will be strong enough to support its intended design load, it must be compacted, made dense. Most specifications will require that the field earthwork be compacted to a specified percent of a target density called maximum density. The nuclear device is one device that is used to determine if the earthwork in the field has met this requirement (in-place density).

To determine the dry density of a soil in-place it is necessary to also determine the moisture content of the soil.

Nuclear Device

The nuclear device is a portable source containing a radioactive source, electronics and rechargeable battery packs. The device uses radiation (a gamma source and a gamma detector) to obtain several different readings. These readings are then calculated to acquire a number for in-place or dry density for soils and soil-aggregate mixtures. Density readings for depths between 50mm and 300mm (2 in. and 12 in.) (depending upon the method used) can be determined.

Summary of Testing

Since a density reading and a moisture reading are required to determine dry density, both values have to be determined. A separate radioactive source is necessary for each technique. The nuclear device may have a radioactive source at the tip of its probe or source rod and another source located in the body of the device. Some devices may have both sources located in the probe. At the back of the device, at opposite ends from the probe are detector tubes (Geiger-Muller tubes). Once the test is underway, these detector tubes pick up or count the gamma rays that travel through the material to them and relay this count to the master controls inside the body of the device. A certain percentage of gamma rays emitted by the source is absorbed by the soil, a certain percentage is scattered in the material and a certain percentage will pass through the material. The detector counts the rays that pass through the material and this count is relayed to the master control, called a scaler, by means of electrical impulses. The number of rays counted depends on the density of the material. The higher the density of the material the lower the gamma ray count.

Moisture

The nuclear gauge uses a fast neutron source and a thermal neutron detector which determines the intensity of slow or moderated neutrons. Moisture is determined by the relationship of nuclear count to mass of water per unit volume of soil. The moisture content is used in conjunction with the density measurement to determine dry density.

Density Testing

Three methods for determining density are covered by AASHTO T 238: Method A, or Backscatter mode, Method B, Direct Transmission, and Method C, Air Gap. Each method uses a different test geometry (the geometric space of the test area changes) and should be used where appropriate. Generally, backscatter is used when the properties of the first few inches are concerned (such as density of hot mix asphalt), and direct transmission is used when the properties of 50 mm - 30 mm (2 in.-12 in.) are concerned (such as 150 mm [6 in.] lifts of compacted backfill).

Air Gap

The air gap method which some older gauge models utilized has now been antiquated by technology.

Direct Transmission

To determine in-place density with a nuclear device, you will first prepare a smooth area on which to place the device. You will then place the nuclear device on the prepared surface and check to be sure that it is solidly seated with maximum contact between the device and the surface of the material being tested. Then place the device to the side and drill a small hole through the layer or lift being tested. Replace the device in the prepared area, in the same

orientation as before, with the probe directly over the hole. Insert the probe into the hole and operated the device in accordance with the manufacturer's instructions.

Backscatter

To determine in-place density in the backscatter mode, perform the test in the same manner as described under Direct Transmission, with the exception of drilling the hole and lowering the probe. Operate the device in backscatter mode in accordance with the manufacturer's instructions.

Special considerations when reporting density measurements as determined by the nuclear gauge: "It should be noted that the volume of soil or soil-aggregate represented in the measurements is indeterminate and will vary with the source - detector geometry of the equipment used and with the characteristics of the material tested. In general, and with all other conditions constant, the more dense the material, the smaller the volume involved in the measurement. The density so determined is not necessarily the average density within the volume involved in the measurement. For the usual density conditions, the total count is largely determined by the upper 75 mm to 100 mm (3 to 4 inches) of soils and soil aggregates.

Common Testing Errors

Test results may be affected by:

- ▶ Soil chemical composition
- ▶ Soil not homogenous
- ▶ Equipment not calibrated properly
- ▶ Surface texture
- ▶ Testing too close to a vertical wall or other mass (e.g., cars, construction equipment, body of water, large pipe)
- ▶ Groups of observers gathered too close to device during operation
- ▶ Presence of asphaltic materials, recycled pcc, cement, lime, flyash, etc. in soil materials

Safety

The device used for density testing is like any other tool you use on the job. It is there to make your job of taking accurate density readings easier and more efficient. It can be dangerous if used improperly. However, this device is different in that the danger it poses is invisible. Radiation poisoning is very serious. This is why taking proper safety precautions is so vital when dealing with this machine at any level. The following safety rules are simple to follow and will cause you very little inconvenience. If you follow them correctly, the nuclear device will be one of the safest tools you use.

There are two important facts to remember when working with nuclear devices. One, the device is radioactive and, two, the device is very expensive. It must always be handled carefully and treated with the utmost respect. It is important to take care of the nuclear device, but it is also important to take care of yourself while you are using it. This section will give guidelines on how to handle the devices with a minimum amount of radiation exposure.

You should not be afraid of radiation, but should have a healthy respect for it. By realizing the dangers involved, you will know the importance of following safety regulations carefully.

PRINCIPLES OF RADIATION SAFETY

There are several principles of radiation safety with which you should be familiar before you handle the nuclear device. These principles are known as the ALARA concept: keep radiation exposure As Low As Reasonably Achievable. The first principle is distance. The further someone is from the device the less the radiation exposure. The amount of radiation a person will receive when around a radioactive source is influenced by three factors: the intensity of the source, the person's distance from the source and the length of time the person is exposed to it. The intensity of radiation is inversely proportional to the square of the distance from the source. This is called the Inverse Square Law. This means, for example, that a certain radiation intensity at 3 m (10 ft) from a source will have 1/4 the intensity that it has 1.5 m (5 ft) from the source. Remember, the device is always radioactive. The on/off switch does not turn off the radiation.

The second principle is time. You must keep your exposure to a minimum. The third principle is shielding. Shielding is a very important part of radiation safety. Even though shielding is built into our equipment, any objects between you and the source help to cut down on the amount of radiation received. We will discuss each of these principles in more detail.

DISTANCE

Distance from the radiation source is the most effective way to keep exposure to a minimum because alpha and beta particles travel only short distances through matter, and gamma rays become less intense as the distance is increased. Doubling the distance from a radioactive source reduces the exposure to one-fourth the original value.

LOUISIANA DEPARTMENT OF NATURAL RESOURCES

Office of Environmental Affairs

NUCLEAR ENERGY DIVISION

NOTICE TO EMPLOYEES

STANDARDS FOR PROTECTION AGAINST RADIATION; NOTICES,
TIONS AND REPORTS TO WORKERS; INSPECTIONS

INSTRUC

In the Louisiana Radiation Regulations, the Environmental control Commission has established standards for your protection against radiation hazards and has established certain provisions for the options of workers engaged in work under a license or registration certificate issued by the Nuclear Energy Division

YOUR EMPLOYER'S RESPONSIBILITY

Your employer is required to

8. Apply these regulations and the conditions of his license or registration certificate to work involving sources of radiation.
9. Post, or otherwise make available to you, a copy of Louisiana Radiation Regulations, registration certificates and operating procedures which apply to work in which you are engaged and to explain their provisions to you.
10. Post all notices of violation involving radiological working conditions, proposed imposition of civil penalties and or orders.

or in the license or registration certificate. The basic limits for radiation dose to employees are set forth in Section D.101, D.103 and D.104 of the regulations. These sections specify limits on radiation dose and exposure to concentrations Of radioactive material in air and water.

2. If you work where personnel monitoring is required, and if You request information on your radiation doses.
 - (a) Upon termination Of your employment, your employer must give you a written report of your radiation dam, and
 - (b) Your employer must advise you annually of your dose from radiation.

YOUR RESPONSIBILITY AS A WORKER

You should familiarize yourself with those provisions of the Louisiana Radiation Regulations and the operating procedures which apply to the work in which you are engaged. You should observe their provisions for your own protection and the protection of your co-workers.

WHAT IS COVERED BY THESE REGULATIONS

1. Limits oil exposure to radiation and radioactive material in restricted and areas;
2. Measures to be taken after accidental exposure;
3. Personnel monitoring, surveys and equipment;
4. Caution signs, labels and safety interlock equipment;
5. Exposure records and reports;
6. Options for workers regarding Division inspections, and
7. Related matters.

REPORTS ON YOUR RADIATION EXPOSURE HISTORY

1. The Louisiana Radiation Regulations require that your employer give you a written report if you receive a radiation dose in excess of any applicable limit asset forth in the regulations

INSPECTIONS

All licensed or registered activities are subject to inspection by representatives of the Nuclear Energy Division. In addition, any worker or representative of workers who believes that there is a violation of the Louisiana Nuclear Energy and Radiation Control Law, the regulations issued thereunder, or the terms Of the employer's license or registration certificate with regard to radiological working conditions in which the worker is engaged, may request an inspection by sending a notice of the alleged violation(s) to the Nuclear Energy Division. The request must set forth the specified grounds for the notice and must be signed by the worker or the representative of the workers. During inspections, Division inspectors may confer privately with workers, and any worker may bring to the attention of the inspectors any past or present condition which he believes contributed to or caused any violation as described above.

INQUIRIES

inquiries dealing with the matters Outlined above Can be directed to:

NUCLEAR ENERGY DIVISION
P. O. Box 14690
Baton Rouge, Louisiana 70898

Copies of this notice must be posted in a sufficient number of places in every establishment where employees are employed in activities licensed or registered by the Nuclear energy Division, pursuant to parts B or C of the Louisiana radiation regulations, to permit employees working in or frequenting any portion of a restricted area to observe a copy on the way to or from their place of employment.

Figure 1 - Notice to Employees Poster

24-HOUR
Telephone
504 925-4518

For this reason, place the device in the back of the vehicle when transporting it. Also, it is a good precaution to store the device at least 7.5 meters (25 ft) away from working areas whenever possible. The device must be properly marked with the radioactive symbol and kept locked when not in use. This means that the device itself must be locked and kept inside the storage case. The room in which the device is stored must also be kept locked. A closet, storage room or a cabinet may be used as the storage area if it meets the criteria described. Ideally, the storage area should have only one door and no windows. The door must have a lock. If storage cabinets are selected as the storage site, the cabinet must be securely and permanently attached to the structure of the facility. Store the nuclear device in its appropriate case.

Designate the area selected as the authorized storage location by installing a permanent sign in clear view, preferably on the access door. The sign is yellow in color, and bears the official symbol and the words "CAUTION - RADIOACTIVE MATERIALS." If a radioactive source is lost or stolen, immediately notify your supervisor. There must also be a "Notice To Employees" sign posted where the device is stored.

TIME

Time of exposure must be monitored carefully so anyone working with the device is checked for exposure to radiation. Each operator or handler of radioactive devices should wear a TLD (Thermoluminescent Dosimetry) badge or similar device, on his or her outer clothing when using or transporting these devices. The amount of radiation to which the wearer has been exposed is indicated by these badges. The badge is checked regularly for radiation exposure. It is replaced by a new badge. The badges are never reused.

Badges are not interchangeable between operators. The badge you are issued is numbered for identification; you must always wear your own badge. Be careful with your badge because it is the means by which your exposure to radiation is measured. Your badge should not be exposed to radiation when you are not wearing it. This means that you should not store your badge in or near the nuclear equipment box. Also, you should not keep your badge on the dashboard of your vehicle. The sun can melt the holder and ruin the badge. If your badge measures exposure, you want to be sure it came from the device and not some other source. Wear your badge on the upper torso, somewhere between the beltline and the top of the head. Ideally, your badge should be worn in the chest area.

SHIELDING

Proper shielding also reduces exposure. The source encapsulation and shielding stop any alpha and beta particles that are produced by the source because the source is well protected. The radioactive sources in most devices are classified as special form, encapsulated sealed sources. With normal device use, no extra shielding methods are required or necessary. However, anything placed between you and a radiation source is a deterrent to radiation penetration. Never attempt to remove the source. As long as the source is intact, it is safe.

You will be required to transport your nuclear device to various sites where testing is needed. The device is to be transported to the testing site in a truck, carry-all or station wagon. The

device is to be kept securely in its case whenever it is not in use.

It must not be jarred. The mechanical and electronic parts of the device are very durable, but the radiation detectors contain fine wires with glass and ceramic seals that can be damaged by severe jarring. Damage to these parts can cause the device to malfunction. During transport, it must be padded and supported to prevent damage. If transported in a truck, the carrying case shall be secured by lock and chain to the truck. Therefore, be careful to never drop the device, leave it in the way of construction equipment, or transport it unsecured.

The most important thing to remember is use common sense. Follow these guidelines for safe operation of the nuclear device:

- ▶ Do not attempt to use the equipment unless you have been authorized to do so and have been properly trained.
- ▶ Keep the source in a “safe” or stored position when not in use.
- ▶ Always wear your safety badge when using the nuclear device.
- ▶ Never exchange your badge or loan it to another operator.
- ▶ All unauthorized personnel should be kept out of the operating area.
- ▶ Keep the nuclear device locked when not in use.
- ▶ Never leave the nuclear device unattended, except when properly stored.
- ▶ Return the nuclear device to its proper storage location when not in use.

Security

Security must always be maintained at 3 levels:

- ▶ Lock on device
- ▶ Device in locked case
- ▶ Device in locked case in locked storage area or locked transport vehicle.

CLEANING

The nuclear device must be kept as clean as possible at all times. Dirt and dust from the field can build up and cause delicate mechanisms within the machine to malfunction. The device must be cleaned before and after use. When cleaning, put the source rod in the safe storage position. This safe position is obtained by making sure that the index rod is pulled up to the top position and that the trigger button is released. To clean the outside of the device, use mild soap and water on a damp cloth. Before use, wipe the bottom of the device with a long handled brush to remove any dust and moisture. Turn the bottom away from you when doing this. Do the same when you are finished taking your reading. Make sure to clean off the

Standardization of Gauge.

Standardization of the gauge is required each day prior to usage or whenever gauge readings are suspect. As per AASHTO T 238, in order to check the standardization the gauge should be turned on and warmed up prior to use according to the manufacturer's instructions (usually 5 minutes, although older models may require up to 20 minutes).

1. Place the gauge on the standard reference block. Take at least four one minute repetitive readings on the block. This constitutes one standardization check.
2. If the mean of four repetitive readings is outside the tolerance allowed by the following equation, take another standardization check (four one minute readings). If the second standardization check is outside the allowable tolerance, the calibration should be checked by the manufacturer.

$$N_s = N_o \pm 1.96\sqrt{N_o}$$

Where

N_s = count currently measured in checking the instrument operation on the reference standard.

N_o = count previously established on the reference standard (mean of 10 repetitive readings)

If the second calibration check is within the allowable tolerance, the gauge is in working order. If it is outside the allowable limits, the manufacturer should check the calibration.

3. If the calibration check shows that no significant change in the calibration has occurred, then a new standard count (N_o) should be established (by taking the average of 10 subsequent standard counts). If the calibration curve is significantly different, repair and recalibrate the instrument.

Procedure (Method A, Backscatter)

1. Select a location where the gauge will be at least 150 mm (6 in.) away from any vertical projection.

Note about Trench Correction

When within 0.6 m (2 ft) of a wall in a trench the gauge might read the hydrogen contained in the wall as well as the material under test. In such a situation use the trench correction program contained within the gauge. This program will instruct you to place the standard block in the trench and then take a second reference count which will be compared to the standard, at which point adjustments (if necessary) will be made.

2. Prepare the test site by removing all loose and disturbed material and additional material as necessary to expose the top of the material to be tested.
3. Plane an area of sufficient size to smooth condition to obtain maximum contact between the gauge and the material being tested.
4. The maximum void space beneath the gauge shall not be more than 3 mm (1/8 in.). Use native fines or fine sand to fill these voids. This filled area should not equal more than 10% of the surface area beneath the gauge. Several trial seatings may be necessary in order to achieve maximum contact between the gauge and the material to be tested.
5. Operate the warmed up and standardized gauge in backscatter mode in accordance with the manufacturer's instructions. Take one or more one-minute readings, which will determine the in-place wet density of the soil.

Procedure (Method B, Direct Transmission)

1. Select a location where the gauge will be at least 150 mm (6 in.) away from any vertical projection. Special considerations may apply when taking readings close to walls in a trench

Note about Trench Correction

When within 0.6 m (2 ft) of a wall in a trench the gauge might read the hydrogen contained in the wall as well as the material under test. In such a situation use the trench correction program contained within the gauge. This program will instruct you to place the standard block in the trench and then take a second reference count which will be compared to the standard, at which point adjustments (if necessary) will be made.

2. Prepare the test site by removing all loose and disturbed material and additional material as necessary to expose the top of the material to be tested.
3. Plane an area of sufficient size to a smooth condition to obtain have maximum contact between the gauge and the material being tested.
4. The maximum void space beneath the gauge shall not be more than 3 mm (1/8 in.). Use native fines or fine sand to fill these voids. This filled area should not equal more than 10% of the surface area beneath the gauge. Several trial seatings may be necessary in order to achieve maximum contact between the gauge and the material to be tested.
5. Make a hole perpendicular to the prepared surface using the guide and hole-forming device. The hole should not cause the gauge to tilt from the plane of the prepared area.
6. Place the gauge over the hole and extend the probe into the hole to the depth required for the test. Seat the gauge firmly by rotating it about the probe in a back and forth motion.
7. Pull gently on the gauge so that the probe will contact the side of the hole toward the center of the gauge. The probe must be in intimate contact with the hole in order to take effective readings.
8. Operate the warmed up and standardized gauge in direct transmission mode in accordance with the manufacturer's instructions. Take one or more one-minute readings, which will determine the in-place wet density of the soil.

Operating a gauge in direct transmission mode is basically to properly setting the prob at correct depth and performing any calibration offsets in order to determine the wet density of the soil. The density gauge also measures moisture content of the area under test and can display an instantly converted dry density value for the test location. Once the correct maximum dry density is determined and entered into the gauge the display may also be expressed as a percentage of the maximum dry density.

Gauges made by different manufacturers have similar, but distinct user interfaces. Operators familiar with the basics of nuclear density testing will probably be able to utilize any gauge style.

Moisture Content Procedure

Once the wet density has been determined and before moving the gauge, set the controls to the MOISTURE MODE and take a series of one or more one-minute readings. The unit will now display the unit weight of water measured. Pressing a control button on most gauges will result in the dry density being displayed automatically. See the manufacturer's instructions to operate your individual unit.

NOTE:

The nuclear device reads hydrogen ions as water. It also can be affected by minerals or chemicals that are neutron absorbers (e.g., boron, cadmium). Because of this, the mineral composition of a soil may cause the moisture content determined by a nuclear device to be inaccurate. Since density and moisture content bear a direct relationship to each other an inaccurate moisture content will yield an inaccurate density reading. To guard against this type of error, you should always clear the moisture content from the nuclear device for a given soil or soil-aggregate with AASHTO T 265 before relying on the nuclear moisture.

Glossary

Background Count	The naturally occurring radiation from lights, the sun and many other sources.
Heterogeneity	Differing in structure, quality, etc.; dissimilar.
Fast Neutron Detector	An electronic device that counts Neutrons as they pass through a special gas.
Fast Neutron Source	Each atom has a nucleus comprised of varying numbers of Protons and Neutrons. When a high-energy electron strikes a nuclei, one or more Protons or Neutrons are released. These neutrons are used to measure moisture content by a nuclear gauge.
Gamma Detector	An electronic device that converts electronic pulses caused by high energy electrons, passing through a special gas enclosed in a tube, into a numerical count.
Gamma Source	A radioactive material that emits high energy electron radiation, similar to x-rays commonly used in hospitals. The radiation is invisible and capable of passing through many millimeters of wood, soil or other material.
Indeterminate	Indefinite or vague.
Radioisotope	Radioactive isotope of a chemical element.
Scaler	A device that converts electric pulses into numerical counts and displays the results.
Spatial	Existing in differing space, or relationships of space.

CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES (UNIFIED SOIL CLASSIFICATION SYSTEM)

ASTM D 2487



Developed by
FHWA Multi-regional Soils Training & Certification Group

NOTE

Successful completion of the following training materials, including examination and performance evaluations are prerequisites for this training package.

- ▶ AASHTO T 265, Laboratory Determination of Moisture Content of Soils
- ▶ AASHTO T 88, Particle Size Analysis of Soil
- ▶ AASHTO T 89, Determining the Liquid Limit of Soil
- ▶ AASHTO T 90, Determining the Plastic Limit and Plasticity Index of Soil
- ▶ ASTM D 2488, Description and Identification of Soils (Visual-Manual Procedure)

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CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES (UNIFIED SOIL CLASSIFICATION SYSTEM)

Soil exists throughout the world in a wide variety of types. Different types of soil exhibit diverse behavior properties. Because the engineering properties of soils are governed by their physical properties, we need to describe and identify soils in terms that will convey this information clearly and accurately.

This standard is the ASTM version of the Unified Soil Classification System. The basis for the classification scheme is the Airfield Classification System developed by A. Casagrande in the early 1940's. It became known as the Unified Classification System when several U.S. government agencies adopted a modified version of the system in 1952.

SUMMARY OF TESTING

This system identifies three major soil divisions: coarse-grained soils, fine-grained soils and highly organic soils. These three divisions are further subdivided into a total of 15 basic soil groups. Based on the results of visual observations and prescribed laboratory tests, a soil can be cataloged according to the basic soil groups, assigned a group symbol(s) and name, and thereby classified.

TYPICAL TEST RESULTS

The test results from this procedure would appear in the following format:

- ▶ Well-Graded Gravel with Sand (GW)
- ▶ Silty Sand with Organic Fines (SM)

COMMON TESTING ERRORS

- ▶ Not careful in reading the charts and tables used in this method, it is very easy to misinterpret the data.
- ▶ Read and record, then verify.

SAMPLE

This procedure is conducted using soil characteristics from other tests; therefore, no sample is required.

TEST METHODOLOGY

Generally, before a soil can be classified by this standard, the particle-size distribution of the material passing the 75 mm sieve and the plasticity characteristics of the minus 425 μm sieve material must be determined. These tests and procedures have already been described in detail in the prerequisite training for this module.

PROCEDURE

Determine into which of the following groups your sample belongs and proceed to that Classification Heading: (the Flow Chart, figure 1, is helpful in understanding the classification method)

- ▶ Classify the soil as *Fine-grained*, if 50% or more of the test specimen passes the 75 μm sieve.
- ▶ Classify the soil as *Coarse-grained*, if more than 50% of the test specimen is retained on the 75 μm sieve.

Classification of Fine-grained Soil (50% or more of the test specimen passes the 75 μm sieve)

1. The soil is an inorganic clay if the position of the plasticity index versus liquid limit plot, Figure 2, falls on or above the “A” line, the plasticity index is greater than 4, and the presence of organic matter does not influence the liquid limit determination.
 - ▶ Classify the soil as *Lean Clay*, (CL), if the liquid limit is less than 50.
 - ▶ Classify the soil as *Fat Clay*, (CH), if the liquid limit is 50 or greater.
 - ▶ Classify the soil as *Silty Clay*, (CL-ML), if the position of the plasticity index versus liquid limit plot falls on or above the “A” line and plasticity index is in the range of 4 to 7.
2. The soil is an inorganic silt if the position of the plasticity index versus liquid limit plot, Figure 2, falls below the “A” line or the plasticity index is less than 4, and the presence of organic material has not influenced the liquid limit determination.
 - ▶ Classify the soil as *silt*, (ML), if the liquid limit is less than 50.
 - ▶ Classify the soil as a *elastic silt*, (MH), if the liquid limit is 50 or greater

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests ^A				Soil classification	
				Group Symbol	Group Name ^B
COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve	Gravels More than 50% of coarse ¹ fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines ^C	$Cu \geq 4$ and $1 \leq Cc \leq 3^E$	GW	Well-graded gravel ^F
			$Cu < 4$ and/or $1 > Cc > 3^E$	GP	Poorly graded gravel ^F
		Sands with Fines More than 12% fines ^D	Fines classify as ML or MH	GM	Silty gravel ^{F,G,H}
			Fines classify as CL or CH	GC	Clayey gravel ^{F,G,H}
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines ^D	$Cu \geq 6$ and $1 \leq Cc \leq 3^E$	SW	Well-graded sand ^I
			$Cu < 6$ and/or $1 > Cc > 3^E$	SP	Poorly graded sand ^I
		Sands with Fines More than 12% fines ^D	Fines classify as ML or MH	SM	Silty sand ^{G,H,I}
			Fines classify as CL or CH	SC	Clayey sand ^{G,H,I}
FINE-GRAINED SOILS 50% OR MORE PASSES THE No. 200 sieve	Silts and clays Liquid limit less than 50	inorganic	$PI > 7$ and plots on or above "A" line ^J	CL	Lean clay ^{K,L,M}
			$PI < 4$ or plots below "A" line ^J	ML	silt ^{K,L,M}
		organic	Liquid limit - oven dried	OL	Organic clay ^{K,L,M,P}
			Liquid limit - not dried		Organic silt ^{K,L,M,Q}
			<0.75		
		Silts and Clays Liquid limit 50 or more	inorganic	PI plots on or above "A" line	CH
	PI plots below "A" Line			MH	Elastic silt ^{K,L,M}
	organic		Liquid limit - oven dried	OH	Organic clay ^{K,L,M,P}
			Liquid limit - not dried		Organic silt ^{K,L,M,Q}
			<0.75		
	HIGHLY ORGANIC SOILS	Primarily organic matter, dark in color, and organic odor			PT
<div><div><div><div><div>Abased on the material passing the 75-mm (3-in.) Sieve</div><div>Bif field sample contained cobbles or boulders, or both add "with cobbles or boulders, or both" to group name.</div><div>Cgravels with 5 to 12% fines require dual symbols: GW-GM well-graded gravel with silt GW-GC well-graded gravel with clay GP-GM poorly graded gravel with silt GP-GC poorly graded gravel with clay</div><div>Dsands with 5 to 12% fines require dual symbols: SW-SM well-graded sand with silt SW-SC well-graded sand with clay SP-SM poorly graded sand with silt SP-SC poorly graded sand with clay</div></div><div><div>E$Cu = D_{60}/D_{10}$</div><div>C$c = (D_{30})^2 / (D_{10} \times D_{60})$</div></div><div><div>Fif soil contains $\geq 15\%$ sand, add "with sand" to group name.</div><div>Gif fines classify as CL-ML, use dual symbol GC-GM, or SC-SM.</div><div>Hif fines are organic, add "with organic fines" to group name.</div><div>Iif soil contains $\geq 15\%$ grael, add "with gravel" to group name.</div><div>Jif atterberg limits plot in hatched area, soil is a CL-ML, silty clay.</div><div>Kif soil contains 15 to 29% plus No. 200, add "with sand or "with gravel," whichever is predominant.</div></div><div><div>Lif soil contains $\geq 30\%$ plus No. 200, predominantly sand, add "sandy" to group name.</div><div>Mif soil contains $\geq 30\%$ plus No. 200, predominantly gravel, add "gravelly" to group name.</div><div>NPI ≥ 4 and plots on or above "A" line.</div><div>OPI < 4 or plots below "A" line.</div><div>PI plots below "A" line.</div></div></div></div></div>					

Figure 1 - Unified Soil Classification Chart

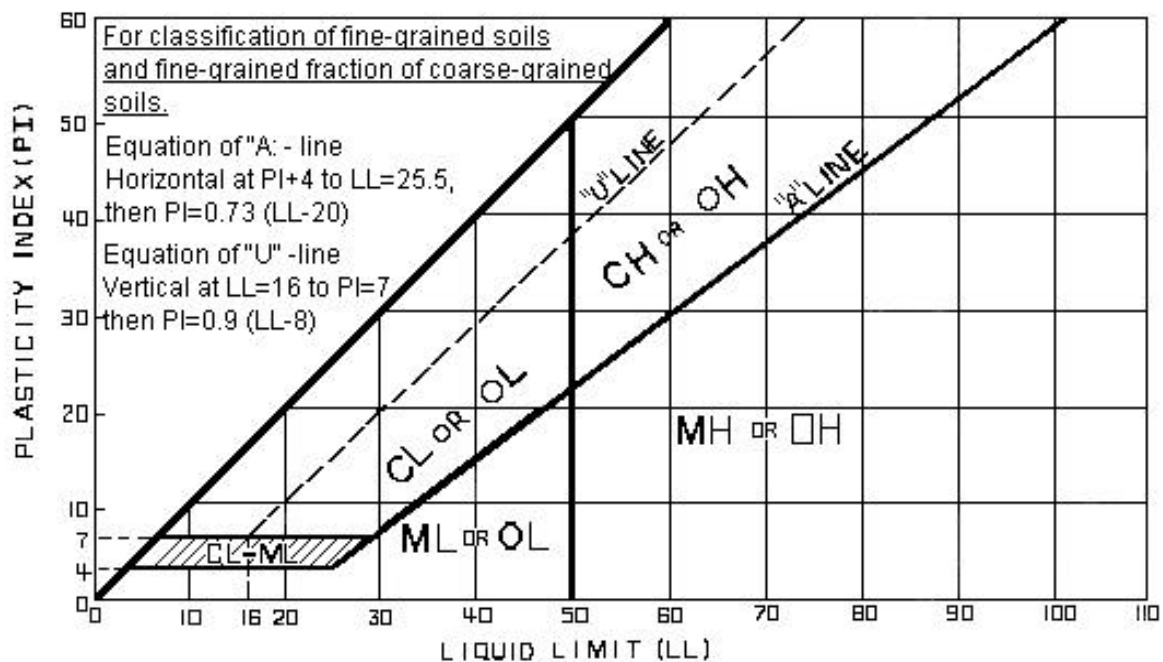


Figure 2 - Plasticity Chart

3. The soil is an organic silt or clay if the organic material is present in sufficient amounts to influence the liquid limit.
 - ▶ If the soil has a dark color and an organic odor when moist and warm, a second liquid limit shall be performed on a test specimen which has been oven dried at $110 \pm 5^\circ \text{C}$ to a constant mass.
 - ▶ The soil is organic silt or organic clay if the liquid limit after oven drying is less than 75% of the liquid limit of the original sample.
 - Classify the soil as an *organic silt* or *organic clay*, (OL), if the liquid limit (not oven dried) is less than 50%. Classify the soil as *organic silt*, (OL), if the plasticity index is less than 4, or the position of the plasticity index versus liquid limit plot, Figure 2, falls below the "A" line. Classify the soil as *organic clay*, (OL), if the plasticity index is 4 or greater and the position of the plasticity index versus liquid limit plot, Figure 2, falls on or above the "A" line.
 - Classify the soil as *organic clay* or *organic silt*, (OH), if the liquid limit (not oven dried) is 50 or greater. Classify the soil as *organic silt*, (OH), if the position of the plasticity index versus liquid limit plot, Figure 2, falls below the "A" line. Classify the soil as *organic clay*, (OH), if the position of the plasticity index versus liquid limit plot, Figure 2, falls on or above the "A" line.
 - ▶ If less than 30%, but 15% or more of the test specimen is retained on the $75 \mu\text{m}$ sieve, the words "with sand" or "with gravel" shall be added to the group name, (based on which ever material is predominant). For example, *lean clay with sand*, (CL); or *silt with gravel*, (ML). If the percent sand is equal to the percent gravel, use "with sand."
 - ▶ If 30% or more of the test specimen is retained on the $75 \mu\text{m}$ sieve, the words "sandy" or "gravelly" shall be added to the group name, (based on whichever

material is predominant). For example: *sandy lean clay*, (CL), or *gravelly fat clay*, (CH). If the percent sand is equal to the percent gravel, use “sandy”.

Classification of coarse-grained soil (more than 50% of the test specimen is retained on the 75 µm sieve)

1. Classify the soil as *gravel*, if more than 50% of the coarse fraction [plus 75 µm sieve] is retained on the 4.75 mm sieve.
2. Classify the soil as *sand*, if 50% or more of the coarse fraction [plus 75 µm sieve] passes the 4.75 mm sieve.
3. If 12% or less of the test specimen passes the 75µm sieve, plot the cumulative particle distribution curve, and compute the coefficient of uniformity, (Cu), and coefficient of curvature, (Cc).

- ▶ Coefficient of curvature,

$$Cc = (D_{30})^2 / D_{10} \times D_{60},$$

Where:

D_{60} , D_{30} and D_{10} are the particle diameters corresponding to 60, 30 and 10% finer on the cumulative particle-size distribution curve, respectively.

- ▶ Coefficient of uniformity,

$$Cu = D_{60} / D_{10},$$

Where:

D_{60} and D_{10} are the particle diameters corresponding to 60 and 10% finer on the cumulative particle-size distribution curve, respectively.

- If less than 5% of the test specimen passes the 75 µm sieve, classify the soil as a *well-graded gravel*, (GW), or *well-graded sand*, (SW); if Cu is greater than 4.0 for gravel or greater than 6.0 for sand, and Cc is at least 1.0 but not more than 3.0.
 - If less than 5% of the test specimen passes the 75 µm sieve, classify the soil as a *poorly-graded gravel*, (GP), or *poorly-graded sand*, (SP), if either the Cu or Cc criteria for well graded soils are not satisfied.
4. If more than 12% of the test specimen passes the 75 µm sieve, the soil shall be considered a coarse-grained soil with fines. The fines are determined to be either silty or clayey based on the plasticity index versus liquid limit plot on Figure 1.

- ▶ Classify the soil as a *clayey gravel*, (GC), or a *clayey sand*, (SC); if the fines are clayey, that is, the position of the plasticity index versus liquid limit plot falls on or above the "A" line and the plasticity index is greater than 7.
 - ▶ Classify the soil as a *silty gravel*, (GM), or a *silty sand*, (SM); if the fines are silty, that is, the position of the plasticity index versus liquid limit plot, falls below the "A" line or the plasticity index is less than 4.
 - ▶ If the fines plot as *silty clay*, (CL-ML), classify the soil as silty, *clayey gravel*, (GC-GM), if it is gravel. Classify the soil as silty, *clayey sand*, (SC-SM), if it is sand.
5. If 5% to 12% of the test specimen passes the 75 μm sieve, give the soil a dual classification using two group symbols.
- ▶ The first group symbol shall correspond to that for gravel or sand having less than 5% fines (GW, GP, SW, SP), and the second symbol shall correspond to gravel or sand having more than 12% fines (GC, GM, SC, SM).
 - ▶ The group name shall correspond to the first group symbol plus "with clay" or "with silt" to indicate the plasticity characteristics of the fines.
6. If the specimen is predominately sand or gravel but contains more than 15% or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name.
7. If the field sample contained cobbles or boulders, or both, the words "with cobbles" or "with cobbles and boulders" shall be added to the group name.

REPORT

The report should include:

- ▶ Group name
- ▶ Group symbol(s)
- ▶ Laboratory test results
- ▶ % Gravel
- ▶ % Sand
- ▶ % Fines
- ▶ and grain-size distribution curve, if it was used to classify the soil.

GLOSSARY

Boulders	- particles of rock that will not pass a 75 mm square opening
Cobbles	- particles of rock that will pass a 300 mm square opening and are retained on a 75 mm sieve.
Coefficient of curvature	- C_c -the ratio $(D_{30})^2/D_{10} \times D_{60}$, where D_{60} , D_{30} and D_{10} are the particle diameters corresponding to 60, 30 and 10% finer on the cumulative particle-size distribution curve, respectively.
Coefficient of uniformity	- C_u -the ratio D_{60}/D_{10} , where D_{60} and D_{10} are the particle diameters corresponding to 60 and 10% finer on the cumulative particle-size distribution curve, respectively.
Gravel	- particles of rock that will pass a 75 mm sieve and be retained on a 4.75 mm sieve with the following sub-divisions: coarse - passes a 75 mm sieve and is retained on a 19 mm sieve. fine - Passes a 19 mm sieve and is retained on a 4.75 mm sieve
Sand	- Particles of rock that will pass a 4.75 mm sieve and be retained on a 0.075 mm sieve with the following sub-divisions: coarse -passes a 4.75 mm sieve and is retained on a 2.00 mm sieve medium -passes a 2.00 mm sieve and is retained on a 0.425 mm fine -passes a 0.425 mm sieve and is retained on a 0.075 mm
Fines	- That material which is non-organic, and passes a 0.075 mm sieve.
Silt	- Soil passing a 0.075 mm sieve that is non-plastic or very slightly plastic and that exhibits little or no strength when air dry. For classification, silt is a fine-grained soil, or the fine-grained portion of soil, with a plasticity index less than 4, and the plot of plasticity index versus liquid limit falls below the "A" line. (see figure 2.)
Clay	- Soil passing the 0.075 mm sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents and that exhibits considerable strength when dry. For classification, a clay is a fine-grained soil, or the fine-grained portion of soil, with a plasticity index greater than 4, and the plot of plasticity index versus liquid limit falls on or above the "A" line. (see figure 1.)
Organic silt	- A silt with sufficient organic content to influence the soil properties. For

- classification , an organic silt is a soil would be classified as a silt except that its liquid limit value after oven drying is less than 75% of its liquid limit value before oven drying.
- Organic clay** - A clay with sufficient organic content to influence the soil properties. For classification , an organic clay is a soil would be classified as a clay except that its liquid limit value after oven drying is less than 75% of its liquid limit value before oven drying.
- Peat** - A soil comprised primarily of vegetable tissue in various stages of decomposition, usually with an organic odor, a dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous (completely decomposed).

The visual-manual procedure covered in this manual utilizes the following group symbols:

- ▶ **G** - gravel
- ▶ **S** - sand
- ▶ **M** - silt
- ▶ **C** - clay
- ▶ **O** - organic
- ▶ **PT** - peat
- ▶ **W** - well graded
- ▶ **P** - poorly graded